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TO ALL WHOM IT MAY CONCERN:

Be it known that WE, Frances E. Lund and Troy D. Randall, citizens of the United States and Santiago Partida-Sánchez, a citizen of Mexico, whose post office addresses are PO Box 59, Saranac Lake, N.Y. have invented an improvement in

CD38 MODULATED CHEMOTAXIS

of which the following is a

SPECIFICATION

1. INTRODUCTION

[0001]   The present invention relates to methods for modulating the migratory activity of cells expressing CD38 for the treatment of disorders including, but not limited to, inflammation, ischemia, asthma, autoimmune disease, diabetes, arthritis, allergies, infection with pathogenic organisms, such as parasites, and transplant rejection. Such cells include, for example, neutrophils, lymphocytes, eosinophils, macrophages and dentritic cells. The invention further relates to drug screening assays designed to identify compounds that modulate the ADP-ribosyl cyclase activity of CD38 and the use of such compounds in the treatment of disorders involving CD38 modulated cell migration. Additionally, the invention relates to the isolation and characterization of a CD38 homologue from the parasitic flatworm, *Schistosoma mansoni*. The identification of such a homologue, referred to

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herein as SM38, provides compositions and assays designed to screen for related enzymes in pathogenic organisms as well as compositions and assays to screen for compounds that modulate the activity and/or expression of SM38. Such compounds can be used to treat pathogenic disorders resulting from infection with such parasites. The invention is based on the discoveries that CD38 ADP-ribosyl cyclase activity is required for chemotaxis and that *S. mansoni* expresses a CD38 homologue that can regulate calcium responses in the parasite.

2. BACKGROUND OF INVENTION

[0002] Hematopoietically-derived cells, including cells such as neutrophils, monocytes, dendritic cells, eosinophils and lymphocytes, are important cellular mediators of the inflammatory response and respond to soluble inflammatory mediators by migration to the site of tissue injury or infection where the newly arrived cells perform their effector functions.

[0003] Neutrophils which represent 40-50 % of the circulating leukocyte population are particularly important to both immunity and inflammation. Neutrophils are normally quiescent cells but upon stimulation can mediate a variety of different inflammatory activities. A large number of different agents are capable of activating neutrophils and this activation is normally mediated by binding of the activating agent to specific receptors expressed on the surface of neutrophils. Once activated, the neutrophils are capable of binding to endothelial cells and migrating to the site of tissue damage, a pathogen or a foreign material. Similarly, eosinophils are also potent inflammatory effector cells, although these cells are most often associated with allergic diseases such as asthma. Like neutrophils, eosinophils have a potent armory of proinflammatory molecules that can initiate

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and maintain inflammatory responses.

[0004]   Once at the inflammatory site, recruited cells such as eosinophils and neutrophils induce

further inflammation by releasing inflammatory products and recruiting other hematopoietically-

derived cells to the site. In some cases, the inflammatory response mediated by the specifically

recruited hematopoietically-derived cells protects the host from morbidity or mortality by eliminating

the infectious agent. In other cases (*i.e.*, autoimmunity, ischemia/reperfusion, transplantation,

allergy), the inflammatory response further damages the tissue resulting in pathology. Thus, agents

which alter inflammation or recruitment of cells may be useful in controlling pathology.

[0005]   Although CD38 expression was at first believed to be restricted to cells of the B cell

lineage, subsequent experiments by a number of groups have demonstrated that CD38 is widely

expressed on both hematopoietic and non-hematopoietically-derived cells. Homologues of CD38

have also been found to be expressed in mammalian stromal cells (Bst-1) and in cells isolated from

the invertebrate Aplysia californica (ADP-ribosyl cyclase enzyme) (Prasad GS, 1996, nature

Structural Biol 3:957-964)

[0006]   More recently, CD38 was shown to be a multifunctional ecto-enzyme with NAD^+

glycohydrolase activity and ADP-ribosyl cyclase activity, enabling it to produce nicotinamide, ADP-

ribose (ADPR), cyclic-ADPR (cADPR) and nicotinic acid adenine dinucleotide phosphate (NAADP)

from its substrates NAD^+ and NADP (Howard et al., 1993 Science 252:1056-1059; Lee et al., 1999

Biol. Chem. 380;785-793). Two of the metabolites produced by CD38, cADPR and NAADP, have

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been shown to induce the release of intracellular calcium in cells isolated from tissues of plants, invertebrates and mammals, suggesting that these metabolites may be global regulators of calcium responses (Lee et al., 1999 Biol. Chem. 380;785-793).

[0007]   Both cADPR and NAADP are known to induce calcium release from calcium stores that are distinct from those controlled by IP^3 receptors (Clapper, DL et al., 1987, J. Biological Chem. 262:9561-9568). Instead, cADPR is believed to regulate calcium release from ryanodine receptor regulated stores, as agonists of ryanodine receptors sensitize cADPR mediated calcium release and antagonists of ryanodine receptors block cADPR dependent calcium release (Galione A et al., 1991, Science 253:143-146).   Thus, it has been proposed that cADPR is likely to regulate calcium responses in tissues such as muscle and pancreas where ryanodine receptors are expressed. Interestingly, it was recently shown that the muscle fibers of the parasitic flatworm, *S. mansoni*, express ryanodine receptors and that agonists of ryanodine receptors such as caffeine can induce intracellular calcium release and muscle contraction in the parasite (Day et al., 2000 Parasitol 120:417-422; Silva et al., 1998, Biochem. Pharmacol 56:997-1003). In mammalian smooth muscle cells, the calcium release in response to acetylcholine can be blocked not only with ryanodine receptor antagonists, but also with specific antagonists of cADPR such as $8-NH^2$-cADPR or 8-Br-cADPR (Guse, AH, 1999, *Cell. Signal.* 11:309-316).

[0008]   These findings, as well as others, indicate that ryanodine receptor agonists/antagonists icnluding cADPR can regulate calcium responses in cells isolated from species as diverse as helminths to mammals, however, it is unclear whether ADP-ribosyl cyclase enzymes such as CD38

or SM38 are required for the production of cADPR *in vivo*. Additionally, there has been no direct evidence to link CD38 enzyme activity with downstream responses such as calcium release, proliferation, apoptosis, migration or other effector functions. Thus, despite the high level expression of CD38 on many cell types, no clear defining role for CD38 enzyme activity in immune responses has been established.

3. SUMMARY OF THE INVENTION

[0009]   The present invention relates to methods for modulating the migratory activity of cells expressing CD38 involving the administration of agonists or antagonists of CD38 enzyme activity, and the cADPR mediated signal transduction pathway, including small molecules, large molecules, and antibodies. The invention also provides for compounds and nucleotide sequences that can be used to modulate CD38 gene expression.

[0010]   The present invention further relates to the isolation and characterization of a CD38 homologue from the parasitic flatworm *Shistosoma mansoni*, herein referred to as SM38. The identification of such a homologue provides compositions and assays designed to screen for related enzymes in pathogenic micro-organisms (such as helminths) as well as compositions and assays to screen for compounds that modulate the activity of SM38. Such compounds can be used to treat pathogenic disorders resulting from infection with such pathogenic micro-organisms.

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[0011]   The invention relates to assays designed to screen for compounds that modulate the enzymatic activity of CD38 and/or SM38 (CD38/SM38), *i.e.*, compounds that act as agonists and antagonists of CD38 enzyme activity. In addition, the screens of the invention may be used to identify substrates of CD38/SM38 that are converted into antagonists or agonists of signal transduction pathways involving cADPR. The screens of the invention also may be used to directly identify agonists and antagonists of signal transduction pathways involving cADPR.

[0012]   The invention also relates to assays designed to screen for compounds that modulate CD38/SM38 gene expression. For example, cell-based assays can be used to screen for compounds that modulate CD38/SM38 transcription such as compounds that modulate expression, production or activity of transcription factors involved in CD38/SM38 gene expression; antisense and ribozyme polynucleotides that modulate translation of CD38/SM38 mRNAs and polynucleotides that form triple helical structures with the CD38/SM38 regulatory regions and inhibit transcription of the CD38/SM38 gene.

[0013]   Identified compounds may be used in the treatment of disorders where the migratory activity of CD38-expresssing cells, such as hematopoietically-derived cells, contributes to the development of such disorders. Such disorders include, but are not limited to inflammation, ischemia, asthma, autoimmune disease, diabetes, arthritis, allergies or transplant rejection where inhibition of migratory activity using, for example, CD38 antagonists would be desired. In contrast, in subjects infected with pathogenic microorganisms or immunosuppressed subjects it may be desirable to induce the migratory activity of hematopoietically-derived cells using, for example,

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agonists of CD38. Additionally, identified compounds may be used to treat pathogenic disorders resulting from infection with pathogenic micro-organisms expressing SM38 or structurally related homologous proteins.

4.   BRIEF DESCRIPTION OF THE FIGURES

[0014]   Figure 1. Normal Cellular Response to Chemoattractant Signaling. (1) Chemoattractant binds to receptor and initiates signaling. (2) CD38 hydrolyzes NAD and produces cADPR, which facilitates Ca2+ release from internal stores. (3) Ca2+ is released from cADPR-controlled internal stores which activates external Ca2+ channel. (4) Extracellular Ca2+ flows into the cell and allows migration.

[0015]   Figure 2. Inhibitors of cADPR Production by CD38 Prevent Capacitative Ca2+ Entry and Chemoattractant Induced Migration (Screens will identify such compounds). (1) Chemoattractant binds to receptor and initiates signaling. (2) Inhibitor of CD38 prevents either hydrolysis of NAD (enzyme is inactive and no products are made) or specifically inhibits production of cADPR (blocks ADP-ribosyl cyclase activity, but enzyme may not be inactive). (3) Lack of cADPR results in no cADPR-mediated Ca2+ release from internal stores. (4) No capacitative Ca2+ influx and no migration.

[0016]   Figure 3. Proteins that Regulate CD38 Enzyme Activity (Screens will identify compounds that activate or inactivate these proteins). (1) Chemoattractant binds to receptor and initiates

signaling. (2) Protein X modifies CD38 and inactivates CD38 enzyme activities. (3) Lack of cADPR

results in no cADPR-mediated Ca2+ release from internal stores. (4) No capacitative Ca2+ influx

and no migration.

[0017] Figure 4. Proteins that Regulate CD38 Expression (Screens will identify compounds that

activate or inactivate these proteins).(1) Chemoattractant binds to receptor and initiates signaling.

(2) Protein X represses CD38 gene transcription. (3) Lack of CD38 results in absence of cADPR

which results in no cADPR-mediated Ca2+ release from internal stores. (4) No capacitative Ca2+

influx and no migration.

[0018] Figure 5. Alternate Substrates for CD38 may generate inhibitors of cADPR and prevent

capacitative Ca2+ release (Screens will identify such compounds). (1) Chemoattractant binds to

receptor and initiates signaling. (2) CD38 hydrolyzes modified substrate (8-BrNAD, for example)and

produces modified product (8-Br-cADPR, for example) (3) Modified product competitively or non-

competitively inhibits cADPR induced Ca2+ release from internal stores. (4) No capacitative Ca2+

influx and no migration.

[0019] Figure 6.   Inhibitors of cADPR binding block capacitative Ca2+ influx. (1)

Chemoattractant binds to receptor and initiates signaling (Screens will identify such compounds).

(2) CD38 hydrolyzes NAD and produces cADPR.   (3) Inhibitor of cADPR (8-Br cADPR)

competitively or non-competitively blocks cADPR induced Ca2+ release from internal stores. (4)

No capacitative Ca2+ influx and no migration.

[0020] Figure. 7. CD38KO mice are more susceptible to S. pneumoniae infection. (a) C57BL/6 WT (open circles) and CD38KO (filled circles) mice were infected intra-tracheally with two doses of S. pneumoniae. The survival of infected animals was monitored over the next 4 days. (b) WT mice that had been irradiated and reconstituted with WT bone marrow (open squares) or CD38KO bone marrow (filled squares) were infected with two doses of S. pneumoniae and monitored for four days. The data are representative of at least 5 independent experiments. n=10 mice/group. (c) WT or Rag-2 KO (open bars) and CD38KO or CD38-Rag-2 double KO (filled bars) mice were infected intra-tracheally with S. pneumoniae and bacterial titers in lung and peripheral blood were determined at 12 hours post-infection. The data are representative of 3 independent experiments. n=10 mice/group. *P<0.001; Student's t test.

[0021] Figure. 8. CD38KO neutrophils are not recruited to the infection site and are unable to chemotax toward bacterially-derived chemoattractants. WT and CD38KO mice were infected intra-tracheally with S. pneumoniae, and the cellular infiltrate in the airways was collected and counted (panel a, WT=open bars and CD38KO=closed bars) at multiple timepoints post-infection. (b) The identity and frequency of the infiltrating cells in the lungs of infected WT and CD38KO mice was determined by microscopic examination (400X magnification) and counting of Diff-Quick stained cytocentrifuge preparations. (c) Differential cell counts in the lung lavage of WT (open bars) and CD38KO (closed bars) mice are presented as the mean number of cells x 10^6 ± (SE). Similar results were obtained in 5 independent experiments. n=5 mice/group/timepoint. *P<0.01 **P=0.01; Student's t Test. (d) Purified bone marrow neutrophils from WT (open bars) and CD38KO mice

(filled bars) were tested for their ability to migrate in response to medium, fMLP or IL-8 in a conventional transwell checkerboard chemokinesis/chemotaxis assay. The number of cells migrating to the bottom chamber of the transwell in the absence of any stimulation was not significantly different between CD38KO and WT neutrophils and ranged from 1500-2300 cells (not shown). The number of neutrophils migrating in response to equivalent concentrations of stimuli in both chambers (chemokinesis) and the number of neutrophils migrating in response to a chemotactic gradient (chemotaxis) is shown. The values shown are the mean ± S.E. of four different experiments. *P <0.001; Student's t Test.

[0022] Figure 9. CD38 expressing neutrophils produce cADPR and release intracellular calcium in response to cADPR and ryanodine. (a) Bone marrow, peripheral blood and peritoneal cavity cells were isolated from WT and CD38KO mice or WT and CD38KO mice that received an intraperitoneal injection of thioglycollate 12 hrs previously. CD38 expression on the Mac-1^{hi}GR-1^{hi} neutrophils was analyzed by flow cytometry. Expression of CD38 on WT neutrophils (solid line histogram) and CD38KO neutrophils (dotted line histogram) is shown. (b) CD15+ human peripheral blood neutrophils were assessed for CD38 expression by staining with anti-CD38 mAb (filled histogram) or an isotype control Ab (dotted line). (c) Cyclase activity was measured in WT and CD38KO bone marrow neutrophils. WT or CD38KO neutrophils were incubated alone (WT=circles and CD38KO=squares) or in the presence of NGD (WT=triangles and CD38KO=diamonds) for 10 minutes. The accumulation of the product, cGDPR, was measured fluorometrically. (d) RyR3 mRNA expression levels were determined by RT-PCR. cDNA was isolated from purified WT bone

marrow neutrophils (PMN) or brain tissue. The amount of input cDNA is indicated. (e-g) Intracellular free calcium levels were measured by FACS in Fluo-3/Fura Red loaded bone marrow neutrophils. (e) Neutrophils were permeabilized with digitonin and then stimulated with ryanodine in the presence (orange line) or absence (blue line) of ruthenium red. (f) Neutrophils were permeabilized in digitonin and then stimulated with cADPR (blue line), heat inactivated cADPR (green line) or 8-Br-cADPR + cADPR (red line). (g) Neutrophils were stimulated with thapsigargin (blue line) or thapsigargin + 8-Br-cADPR (red line). All data in panels e-g are representative of at least three independent experiments.

[0023] Figure 10. CD38 catalyzed cADPR regulates intracellular calcium release, extracellular calcium influx and chemotaxis in neutrophils. (a-c) Intracellular free calcium levels were measured by FACS in Fluo-3/Fura Red loaded bone marrow neutrophils. (a) CD38KO (red line) and WT (blue line) neutrophils were stimulated with fMLP or IL-8 in calcium-free buffer. (b) CD38KO (red line) and WT (blue line) neutrophils were stimulated with fMLP or IL-8 in calcium-containing buffer. (c) CD38KO (red line) and WT (blue line) neutrophils were preincubated in calcium-containing medium ± 8-Br-cADPR and then stimulated with fMLP or IL-8. All data in panels a-c are representative of at least five independent experiments. (d) WT neutrophils were pre-incubated with medium, EGTA or 8-Br-cADPR and then placed in the top chamber of a transwell that contained fMLP or IL-8 in the bottom chamber. The cells that migrated to the bottom chamber in response to the chemotactic gradient were collected and enumerated by flow cytometry. Values shown are mean ± S.E. from three separate experiments with three wells/experimental condition.

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**P=0.008; Mann Whitney Rank Sum Test.

[0024] Figure 11. An NAD+ analogue regulates calcium influx and chemotaxis in fMLP-activated neutrophils. (a) Dye-loaded purified bone marrow neutrophils from WT mice were preincubated in medium (blue line) or increasing concentrations of N(8-Br-A)D+ (red line) and then stimulated with fMLP. Changes in intracellular calcium levels were measured by flow cytometry. The data are representative of three independent experiments. (b-c) WT (left panel) and CD38KO (right panel) neutrophils were preincubated with medium (filled bars) or N(8-Br-A)D+ (open bars) and then placed in the top chamber of a transwell which contained fMLP (panel b) or IL-8 (panel c) in the bottom chamber. The cells that migrated to the bottom chamber in response to the chemotactic gradient were collected and enumerated by flow cytometry. Values shown are mean ± S.E. from three separate experiments with three wells/experimental condition. *P<0.001 Student's t Test.

[0025] Figure 12 A-B. The recruitment of neutrophils and eosinophils to the lungs in a model of allergic asthma is impaired in CD38 KO mice. Naive CD4 T cells from WT C57BL/6 mice or OVA-primed CD4 T cells from WT C57BL/6 mice were transferred to either WT C57BL/6 mice or to CD38KO-C57BL/6 mice as indicated. Recipient mice were subsequently challenged on 7 consecutive days by intratracheal instillation of 10 µg OVA in PBS. Neutrophils (A) and eosinophils (B) in the lung lavage on the eighth day after initial challenge were enumerated by microscopic examination (400X) of Diff-Quick stained cytocentrifuge preparations

[0026] Figure 13. Comparison of *S. mansoni* SM38 cDNA with *S. mansoni* ESTs. The SM38

cDNA was isolated and cloned from an *S. mansoni* cDNA library as described in methods. The cDNA for SM38 includes 5' untranslated sequence (gray box), an initiation methionine (underlined), an open reading frame encoding a 303 amino acid protein (clear box), a stop codon (underlined), 3' untranslated sequence (gray box) and a poly-adenylation site (underlined). The full-length cDNA was compared to published *S. mansoni* EST sequences and three separate EST sequences were found that were identical to portions of the SM38 sequence. The SM38 cDNA includes 421 base pairs of unique sequence (70 bp 5' untranslated and 351 bp of open reading frame) not found in any public database.

[0027]   Figure 14. Translation of SM38 cDNA. The SM38 cDNA was translated in all reading frames and an open reading frame of 303 amino acids was identified. The initiation codon is located at nucleotide position 71-73 and the termination codon is found at nucleotide position 980-983.

[0028]   Figure 15. SM38 is homologous to Aplysia ADP-ribosyl cyclase and human CD38 cyclase. The protein sequence of SM38 was aligned with the protein sequences for Aplysia ADP-ribosyl cyclase (part a) and human ADP-ribosyl cyclase CD38 (part b). A high degree of homology (boxed residues) was observed with 21% identity between the Aplysia protein and SM38 and 23% identity between human CD38 and SM38. The conserved 10 cysteine residues present in all members of the cyclase protein family are also present in SM38 (shaded boxes). The two additional cysteines found in CD38 (underlined), but not in Aplysia, are also lacking in SM38. However, the SM38 protein contains two additional cysteine residues that are unique and are not found in either CD38 or Aplysia cyclase (underline). Most importantly, the active site catalytic residues identified for CD38 and

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Aplysia enzyme (starred residues) are also present in SM38.

[0029] Figure 16. SM38 is a soluble protein. The protein sequence of SM38 was examined to determine if the protein is a type-II membrane bound protein like CD38, a soluble protein like the Aplysia cyclase, a GPI-linked protein like other cyclase family proteins, or a secreted protein. The conserved enzyme domain (see previous figure) is shaded. SM38 contains only 22 amino acids 5' of the enzyme domain. These 22 amino acids are not hydrophobic, thus, no leader sequence 5' of the enzyme domain could be identified, indicating that SM38 is not secreted or GPI-linked. Additionally, no 5' transmembrane domain could be identified, indicating that SM38 is not a type-II membrane protein. Therefore, SM38 is most likely a soluble cytoplasmic protein like Aplysia cyclase.

[0030] Figure 17. Reverse translation of SM38. The 303 amino acid coding region of SM38 was reverse-translated to identify a degenerate DNA sequence that would encode the SM38 protein.

5.   DETAILED DESCRIPTION OF THE INVENTION

[0031] The present invention relates to methods for modulating the migratory activity of cells involving the regulation of CD38 ADP-ribosyl cyclase activity. The invention is based on the discovery that granulocytes such as neutrophils and eosinophils from CD38KO mice cannot be efficiently recruited to sites of inflammation and infection in the body. The invention is based on the discovery that although CD38 ADP-ribosyl cyclase activity is not essential for the initial

activation of granulocytes such as neutrophils, it is critically important in regulating neutrophil

chemotaxis both *in vivo* and *in vitro*. In particular, cADPR, a product of CD38 ADP-ribosyl cyclase

activity, is required to induce calcium release from calcium stores present within neutrophils. The

release of calcium from this specialized store is necessary for activation and opening of plasma

membrane channels resulting in a capacitative influx of calcium that subsequently mediates the

direct migration of neutrophils toward chemoattractants and/or inflammatory products.

[0032]   The present invention encompasses screening assays designed for the identification of

modulators, such as agonists and antagonists, of CD38 enzyme activity and/or modulators of cADPR

dependent calcium responses and chemotaxis.   The invention further relates to the use of such

modulators in the treatment of disorders based on the CD38 controlled migratory activity of cells to

chemoattractants and inflammatory products.   Such disorders include, but are not limited to,

inflammation, ischemia, autoimmune disease, asthma, diabetes, arthritis, allergies, infections and

organ transplant rejection.

[0033]   The present invention also relates to the identification, isolation and characterization of the

CD38 homologue, SM38, from the parasite *S. mansoni*. The invention encompasses screening

assays to identify related enzymes in other pathogenic micro-organisms, such as helminths, as well

as compositions and assays to screen for compounds that modulate the activity and expression of

SM38. The invention further relates to the use of such modulators to treat pathogenic disorders in

animals and humans infected with organisms expressing SM38 or structurally related molecules.

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[0034] Various aspects of the invention are described in greater detail in the subsections below.

5.1. THE *SM38* GENE

[0035] The cDNA sequence and deduced amino acid sequence of *S. mansoni* SM38 is shown in Figure 14 (ATCC Deposit No:). The SM38 cDNA was translated in all reading frames and an open reading frame of 303 amino acids was identified. The initiation codon is located at nucleotide position 71 and the termination codon is found at nucleotide position 981.

[0036] The *SM38* nucleotide sequences of the invention include: (a) the DNA sequences shown in Figure 14; (b) a nucleotide sequences that encodes the amino acid sequence shown in Figure 14; (c) any nucleotide sequence that (i) hybridizes to the nucleotide sequence set forth in (a) or (b) under stringent conditions, e.g., hybridization to filter-bound DNA in 0.5 M NaHPO$_4$, 7% sodium dodecyl sulfate (SDS), 1 mM EDTA at 65°C, and washing in 0.1xSSC/0.1% SDS at 68°C (Ausubel F.M. et al., eds., 1989, Current Protocols in Molecular Biology, Vol. I, Green Publishing Associates, Inc., and John Wiley & sons, Inc., New York, at p. 2.10.3) and (ii) encodes a functionally equivalent gene product; and (d) any nucleotide sequence that hybridizes to a DNA sequence that encodes the amino acid sequence shown in Figure 14 under less stringent conditions, such as moderately stringent conditions, e.g., washing in 0.2xSSC/0.1% SDS at 42°C (Ausubel et al., 1989 supra), yet which still encodes a functionally equivalent SM38 gene product. Functional equivalents of the SM38 protein include naturally occurring SM38 present in species other than *S. mansoni*. The invention also includes degenerate variants of sequences (a) through (d). The invention also includes nucleic acid molecules, that may encode or act as *SM38* antisense molecules, useful, for example, in *SM38* gene

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regulation (for and/or as antisense primers in amplification reactions of *SM38* gene nucleic acid sequences).

[0037]   In addition to the *SM38* nucleotide sequences described above, homologs of the *SM38* gene present in other species can be identified and readily isolated, without undue experimentation, by molecular biological techniques well known in the art. For example, cDNA libraries, or genomic DNA libraries derived from the organism of interest can be screened by hybridization using the nucleotides described herein as hybridization or amplification probes.

[0038]   The invention also encompasses nucleotide sequences that encode mutant SM38s, peptide fragments of the SM38, truncated SM38, and SM38 fusion proteins. These include, but are not limited to nucleotide sequences encoding polypeptides or peptides corresponding to the cyclase domain of SM38 or portions of this domain; truncated SM38s in which the domain is deleted, e.g., a functional SM38 lacking all or a portion of the cyclase region. Certain of these truncated or mutant SM38 proteins may act as dominant-negative inhibitors of the native SM38 protein. Nucleotides encoding fusion proteins may include but are not limited to full length SM38, truncated SM38 or peptide fragments of SM38 fused to an unrelated protein or peptide such as an enzyme, fluorescent protein, luminescent protein, *etc.*, which can be used as a marker.

[0039]   *SM38* nucleotide sequences may be isolated using a variety of different methods known to those skilled in the art. For example, a cDNA library constructed using RNA from cells or tissue known to express *SM38* can be screened using a labeled *SM38* probe. Alternatively, a genomic

library may be screened to derive nucleic acid molecules encoding the SM38 protein. Further, *SM38* nucleic acid sequences may be derived by performing PCR using two oligonucleotide primers designed on the basis of the *SM38* nucleotide sequences disclosed herein. The template for the reaction may be cDNA obtained by reverse transcription of mRNA prepared from cell lines or tissue known to express SM38.

[0040] The invention also encompasses (a) DNA vectors that contain any of the foregoing *SM38* sequences and/or their complements (i.e., antisense); (b) DNA expression vectors that contain any of the foregoing *SM38* sequences operatively associated with a regulatory element that directs the expression of the SM38 coding sequences; (c) genetically engineered host cells that contain any of the foregoing *SM38* sequences operatively associated with a regulatory element that directs the expression of the SM38 coding sequences in the host cell; and (d) transgenic mice or other organisms that contain any of the foregoing SM38 sequences. As used herein, regulatory elements include but are not limited to inducible and non-inducible promoters, enhancers, operators and other elements known to those skilled in the art that drive and regulate expression.

5.1.2. SM38 PROTEINS AND POLYPEPTIDES

[0041] SM38 protein, polypeptides and peptide fragments, mutated, truncated or deleted forms of the SM38 and/or SM38 fusion proteins can be prepared for a variety of uses, including but not limited to the generation of antibodies, the identification of other cellular gene products involved in the regulation of SM38 activity, and the screening for compounds that can be used to modulate the activity of SM38.

[0042]   Figure 14 shows the deduced amino acid sequence of the SM38 protein. The SM38 amino acid sequences of the invention include the amino acid sequence shown in Figure 14. Further, SM38s of other species are encompassed by the invention. In fact, any SM38 protein encoded by the *SM38* nucleotide sequences described above is within the scope of the invention.

[0043]   The invention also encompasses proteins that are functionally equivalent to the SM38 encoded by the nucleotide sequences described in Section 5.1, as judged by any of a number of criteria, including but not limited to the ability to catalyze the production of the calcium mobilizing second messenger, cADPR and thereby regulate calcium response. Such functionally equivalent SM38 proteins include but are not limited to proteins having additions or substitutions of amino acid residues within the amino acid sequence encoded by the *SM38* nucleotide sequences described, above, in Section 5.1, but which result in a silent change, thus producing a functionally equivalent gene product.

[0044]   Peptides corresponding to one or more domains of SM38 as well as fusion proteins in which the full length SM38, a SM38 peptide or a truncated SM38 is fused to an unrelated protein are also within the scope of the invention and can be designed on the basis of the *SM38* nucleotide and SM38 amino acid sequences disclosed herein. Such fusion proteins include fusions to an enzyme, fluorescent protein, or luminescent protein which provide a marker function.

[0045]   While the SM38 polypeptides and peptides can be chemically synthesized (e.g., see Creighton, 1983, Proteins: Structures and Molecular Principles, W.H. Freeman & Co., N.Y.), large

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polypeptides derived from SM38 and the full length SM38 itself may be advantageously produced by recombinant DNA technology using techniques well known in the art for expressing a nucleic acid containing *SM38* gene sequences and/or coding sequences. Such methods can be used to construct expression vectors containing the *SM38* nucleotide sequences described in Section 5.1 and appropriate transcriptional and translational control signals. These methods include, for example, *in vitro* recombinant DNA techniques, synthetic techniques, and *in vivo* genetic recombination. (See, for example, the techniques described in Sambrook et al., 1989, *supra*, and Ausubel et al., 1989, *supra*).

[0046] A variety of host-expression vector systems may be utilized to express the *SM38* nucleotide sequences of the invention. Where the SM38 peptide or polypeptide is expressed as a soluble derivative and is not secreted, the peptide or polypeptide can be recovered from the host cell. Alternatively, where the SM38 peptide or polypeptide is secreted the peptide or polypeptides may be recovered from the culture media. Purification or enrichment of the SM38 from such expression systems can be accomplished using appropriate detergents and lipid micelles and methods well known to those skilled in the art. Such engineered host cells themselves may be used in situations where it is important not only to retain the structural and functional characteristics of the SM38, but to assess biological activity, *i.e.,* in drug screening assays.

[0047] The expression systems that may be used for purposes of the invention include but are not limited to microorganisms such as bacteria transformed with recombinant bacteriophage, plasmid or cosmid DNA expression vectors containing *SM38* nucleotide sequences; yeast transformed with

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recombinant yeast expression vectors containing *SM38* nucleotide sequences or mammalian cell systems harboring recombinant expression constructs containing promoters derived from the genome of mammalian cells or from mammalian viruses.

[0048]   Appropriate expression systems can be chosen to ensure that the correct modification, processing and sub-cellular localization of the SM38 protein occurs. To this end, host cells which possess the ability to properly modify and process the SM38 protein are preferred. For long-term, high yield production of recombinant SM38 protein, such as that desired for development of cell lines for screening purposes, stable expression is preferred. Rather than using expression vectors which contain origins of replication, host cells can be transformed with DNA controlled by appropriate expression control elements and a selectable marker gene, *i.e., tk, hgprt, dhfr, neo*, and *hygro* gene, to name a few. Following the introduction of the foreign DNA, engineered cells may be allowed to grow for 1-2 days in enriched media, and then switched to a selective media. Such engineered cell lines may be particularly useful in screening and evaluation of compounds that modulate the endogenous activity of the SM38 gene product.

5.1.3. TRANSGENIC ANIMALS

[0049]   The SM38 gene products can also be expressed in transgenic animals. Animals of any species, including, but not limited to, mice, rats, rabbits, guinea pigs, pigs, micro-pigs, goats, and non-human primates, e.g., baboons, monkeys, and chimpanzees may be used to generate SM38 transgenic animals.

[0050]   Any technique known in the art may be used to introduce the *SM38* transgene into animals to produce the founder lines of transgenic animals. Such techniques include, but are not limited to pronuclear microinjection (Hoppe, P.C. and Wagner, T.E., 1989, U.S. Pat. No. 4,873,191); retrovirus mediated gene transfer into germ lines (Van der Putten et al., 1985, *Proc. Natl. Acad. Sci. USA* 82:6148-6152); gene targeting in embryonic stem cells (Thompson et al., 1989, *Cell*, 56:313-321); electroporation of embryos (Lo, 1983, *Mol Cell. Biol.* 3:1803-1814); and sperm-mediated gene transfer (Lavitrano et al., 1989, *Cell* 57:717-723); etc. For a review of such techniques, see Gordon, 1989, *Transgenic Animals, Intl. Rev. Cytol.* 115:171-229, which is incorporated by reference herein in its entirety.

[0051]   The present invention provides for transgenic animals that carry the *SM38* transgene in all their cells, as well as animals which carry the transgene in some, but not all their cells, *i.e.,* mosaic animals. The transgene may also be selectively introduced into and activated in a particular cell type by following, for example, the teaching of Lasko et al., (Lasko, M. et al., 1992, *Proc. Natl. Acad. Sci. USA* 89:6232-6236). The regulatory sequences required for such a cell-type specific activation will depend upon the particular cell type of interest, and will be apparent to those of skill in the art. When it is desired that the *SM38* transgene be integrated into the chromosomal site of the endogenous *SM38* gene, gene targeting is preferred. Briefly, when such a technique is to be utilized, vectors containing some nucleotide sequences homologous to the endogenous *SM38* gene are designed for the purpose of integrating, via homologous recombination with chromosomal sequences, into and disrupting the function of the nucleotide sequence of the endogenous *SM38* gene.

[0052] Once transgenic animals have been generated, the expression of the recombinant *SM38* gene may be assayed utilizing standard techniques. Initial screening may be accomplished by Southern blot analysis or PCR techniques to analyze animal tissues to assay whether integration of the transgene has taken place. The level of mRNA expression of the transgene in the tissues of the transgenic animals may also be assessed using techniques which include but are not limited to Northern blot analysis of tissue samples obtained from the animal, *in situ* hybridization analysis, and RT-PCR. Samples of *SM38* gene-expressing tissue may also be evaluated immunocytochemically using antibodies specific for the *SM38* transgene product.

5.4. ANTIBODIES TO SM38 PROTEINS

[0053] Antibodies that specifically recognize one or more epitopes of SM38, or epitopes of conserved variants of SM38, or peptide fragments of SM38 are also encompassed by the invention. Such antibodies include but are not limited to polyclonal antibodies, monoclonal antibodies (mAbs), humanized or chimeric antibodies, single chain antibodies, Fab fragments, F(ab')$_2$ fragments, fragments produced by a Fab expression library, anti-idiotypic (anti-Id) antibodies, and epitope-binding fragments of any of the above.

[0054] The antibodies of the invention may be used, for example, in conjunction with compound screening schemes, as described, below, for the evaluation of the effect of test compounds on expression and/or activity of the SM38 gene product.

[0055] For production of antibodies, various host animals may be immunized by injection with

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a SM38 protein, or SM38 peptide. Such host animals may include but are not limited to rabbits, mice, and rats, to name but a few. Various adjuvants may be used to increase the immunological response, depending on the host species, including but not limited to Freund's (complete and incomplete), mineral gels such as aluminum hydroxide, surface active substances such as lysolecithin, pluronic polyols, polyanions, peptides, oil emulsions, keyhole limpet hemocyanin, dinitrophenol, and potentially useful human adjuvants such as BCG (Bacille Calmette-Guerin) and *Corynebacterium parvum.*

[0056]   Polyclonal antibodies comprising heterogeneous populations of antibody molecules, may be derived from the sera of the immunized animals. Monoclonal antibodies may be obtained by any technique which provides for the production of antibody molecules by continuous cell lines in culture. These include, but are not limited to, the hybridoma technique of Kohler and Milstein, (1975, *Nature* **256**:495-497; and U.S. Patent No. 4,376,110), the human B-cell hybridoma technique (Kosbor et al., 1983, *Immunology Today* **4**:72; Cole et al., 1983, *Proc. Natl. Acad. Sci.* USA **80**:2026-2030), and the EBV-hybridoma technique (Cole et al., 1985, *Monoclonal Antibodies And Cancer Therapy*, Alan R. Liss, Inc., pp. 77-96). Such antibodies may be of any immunoglobulin class including IgG, IgM, IgE, IgA, IgD and any subclasses thereof. The hybridoma producing the mAb of this invention may be cultivated *in vitro* or *in vivo.* Production of high titres of Mabs *in vivo* makes this the presently preferred method of production.

[0057]   In addition, techniques developed for the production of "chimeric antibodies" by splicing the genes from a mouse antibody molecule of appropriate antigen specificity together with genes

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from a human antibody molecule of appropriate biological activity can be used (Morrison et al., 1984, *Proc. Nat'l. Acad. Sci.*, **81**:6851-6855; Neuberger et al., 1984, *Nature*, **312**: 604-608; Takeda et al. 1985, Nature **314**: 452-454). Alternatively, techniques developed for the production of humanized antibodies (U.S. Patent No. 5,585,089) or single chain antibodies (U.S. Patent No. 4,946,778 Bird, 1988, Science **242**: 423-426; Huston et al., 1988, *Proc. Nat'l. Acad. Sci USA*, **85**: 5879-5883; and Ward et al., 1989, *Nature* **334**: 544-546) may be used to produce antibodies that specifically recognize one or more epitopes of SM38.

5.2. SCREENING ASSAYS FOR COMPOUNDS USEFUL IN MODULATING THE ACTIVITY OF CD38/SM38

[0058] The present invention relates to screening assay systems designed to identify compounds or compositions that modulate CD38/SM38 enzyme activity, cADPR mediated signal transduction, or CD38/SM38 gene expression, and thus, may be useful for modulation of cell migration or treatment of infection.

5.2.1. RECOMBINANT EXPRESSION OF CD38

[0059] For purposes of developing screening assays designed to identify compounds or compositions that modulate CD38/SM38 activity it may be necessary to recombinantly express the CD38/SM38 proteins. The cDNA sequence and deduced amino acid sequence of CD38 has been characterized from several species including human, murine and rat as described in Jackson, D.G. et al., 1990, *J. Immunol.* 151:3111-3118; Koguma, T. et al., 1994, *Biochim Biophys Acta* 1224:160-162 and Harada N et al., 1993, *J Immunol* 151:3111-3118, incorporated herein by reference. In

addition, the cDNA and deduced amino acid sequence of *Shistosoma mansoni*, as described herein

may be utilized to recombinantly express the CD 38 homologue, SM38, protein.

[0060]   *CD38/SM38* nucleotide sequences may be isolated using a variety of different methods

known to those skilled in the art. For example, a cDNA library constructed using RNA from a tissue

known to express *CD38/SM38* can be screened using a labeled *CD38/SM38* probe. Alternatively,

a genomic library may be screened to derive nucleic acid molecules encoding the *CD38/SM38*

protein. Further, *CD38/SM38* nucleic acid sequences may be derived by performing a polymerase

chain reaction (PCR) using two oligonucleotide primers designed on the basis of known *CD38/SM38*

nucleotide sequences. The template for the reaction may be cDNA obtained by reverse transcription

of mRNA prepared from cell lines or tissue known to express CD38/SM38 .

[0061]   CD38/SM38 protein, polypeptides and peptide fragments, mutated, truncated or deleted

forms of CD38/SM38 and/or CD38/SM38 fusion proteins can be prepared for a variety of uses,

including but not limited to the generation of antibodies, the identification of other cellular gene

products involved in the regulation of CD38/SM38 mediated cell migration, and the screening for

compounds that can be used to modulate cell migration. CD38/SM38 fusion proteins include fusions

to an enzyme, fluorescent protein, a polypeptide tag or luminescent protein which provide a marker

function.

[0062]   While the CD38/SM38 polypeptides and peptides can be chemically synthesized (e.g., see

Creighton, 1983, Proteins: Structures and Molecular Principles, W.H. Freeman & Co., N.Y.), large

polypeptides derived from CD38/SM38 and the full length CD38/SM38 itself may be advantageously produced by recombinant DNA technology using techniques well known in the art for expressing a nucleic acid containing CD38/SM38 gene sequences and/or coding sequences. Such methods can be used to construct expression vectors containing the CD38/SM38 nucleotide sequences and appropriate transcriptional and translational control signals. These methods include, for example, *in vitro* recombinant DNA techniques, synthetic techniques, and *in vivo* genetic recombination. (See, for example, the techniques described in Sambrook et al., 1989, *supra*, and Ausubel et al., 1989, *supra*).

[0063]   A variety of host-expression vector systems may be utilized to express the CD38/SM38 nucleotide sequences. Where the CD38/SM38 peptide or polypeptide is expressed as a soluble protein or derivative (*e.g.*, peptides corresponding to the intracellular or extracellular domain) and is not secreted, the peptide or polypeptide can be recovered from the host cell. Alternatively, where the CD38 peptide or polypeptide is secreted the peptide or polypeptides may be recovered from the culture media. However, the expression systems also include engineered host cells that express CD38/SM38 or functional equivalents, anchored in the cell membrane. Purification or enrichment of the CD38/SM38 from such expression systems can be accomplished using appropriate detergents and lipid micelles and methods well known to those skilled in the art. Such engineered host cells themselves may be used in situations where it is important not only to retain the structural and functional characteristics of the CD38/SM38 , but to assess biological activity, *i.e.,* in drug screening assays.

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[0064]   The expression systems that may be used for purposes of the invention include but are not limited to microorganisms such as bacteria transformed with recombinant bacteriophage, plasmid or cosmid DNA expression vectors containing *CD38/SM38* nucleotide sequences; yeast transformed with recombinant yeast expression vectors containing *CD38/SM38* nucleotide sequences or mammalian, helminth or insect cell systems harboring recombinant expression constructs containing promoters derived from the genome of mammalian, helminth or insect cells or from mammalian or insect viruses.

[0065]   Appropriate expression systems can be chosen to ensure that the correct modification, processing and sub-cellular localization of the CD38/SM38 protein occurs. To this end, eukaryotic host cells which possess the ability to properly modify and process the CD38/SM38 protein are preferred. For long-term, high yield production of recombinant CD38/SM38 protein, such as that desired for development of cell lines for screening purposes, stable expression is preferred. Rather than using expression vectors which contain origins of replication, host cells can be transformed with DNA controlled by appropriate expression control elements and a selectable marker gene, *i.e., tk, hgprt, dhfr, neo,* and *hygro* gene, to name a few. Following the introduction of the foreign DNA, engineered cells may be allowed to grow for 1-2 days in enriched media, and then switched to a selective media. Such engineered cell lines may be particularly useful in screening and evaluation of compounds that modulate the endogenous activity of the CD38/SM38 gene products.

5.2.2.   NON-CELL BASED ASSAYS

[0066]   In accordance with the invention, non-cell based assay systems may be used to identify compounds that interact with, *i.e.*, bind to CD38, and regulate the enzymatic activity of CD38. Such compounds may act as antagonists or agonists of CD38 enzyme activity and may be used to regulate cell migration including but not limited to hematopoietically derived cells. Additionally, such compounds may be used to regulate the growth, muscle contractility, differentiation, maturation and reproduction of pathogenic micro-organisms expressing SM38 or structurally related homologues. Recombinant CD38/SM38 , including peptides corresponding to different functional domains or CD38/SM38 fusion proteins may be expressed and used in assays to identify compounds that interact with CD38/SM38 .

[0067]   To this end, soluble CD38/SM38 may be recombinantly expressed and utilized in non-cell based assays to identify compounds that bind to CD38/SM38.   Recombinantly expressed CD38/SM38 polypeptides or fusion proteins containing one or more of the CD38/SM38 functional domains may be prepared as described above, and used in the non-cell based screening assays. For example, the full length CD38/SM38 , or a soluble truncated CD38/SM38 , *e.g.*, in which the one or more of the cytoplasmic and transmembrane domains is deleted from the molecule, a peptide corresponding to the extracellular domain, or a fusion protein containing the CD38/SM38 extracellular domain fused to a protein or polypeptide that affords advantages in the assay system (e.g., labeling, isolation of the resulting complex, etc.) can be utilized.   Where compounds that interact with the cytoplasmic domain are sought to be identified, peptides corresponding to the CD38

cytoplasmic domain and fusion proteins containing the CD38 cytoplasmic domain can be used.

[0068]   The CD38/SM38 protein may also be one which has been fully or partially isolated from cell membranes or from the cytosol of cells, or which may be present as part of a crude or semi-purified extract. As a non-limiting example, the CD38 protein may be present in a preparation of cell membranes and the SM38 protein may be present in a preparation of cell cytosol. In particular embodiments of the invention, such cell membranes may be prepared using methods known to those of skill in the art.

[0069]   The principle of the assays used to identify compounds that bind to CD38/SM38 involves preparing a reaction mixture of the CD38/SM38 and the test compound under conditions and for time sufficient to allow the two components to interact and bind, thus forming a complex which can be removed and/or detected in the reaction mixture. The identity of the bound test compound is then determined.

[0070]   The screening assays are accomplished by any of a variety of commonly known methods. For example, one method to conduct such an assay involves anchoring the CD38/SM38 protein, polypeptide, peptide, fusion protein or the test substance onto a solid phase and detecting CD38/test compound or SM38/test compond complexes anchored on the solid phase at the end of the reaction. In one embodiment of such a method, the CD38/SM38 reactant is anchored onto a solid surface, and the test compound, which is not anchored, may be labeled, either directly or indirectly.

[0071]   In practice, microtitre plates conveniently can be utilized as the solid phase. The anchored

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component is immobilized by non-covalent or covalent attachments. The surfaces may be prepared in advance and stored. In order to conduct the assay, the non-immobilized component is added to the coated surfaces containing the anchored component. After the reaction is completed, unreacted components are removed (e.g., by washing) under conditions such that any complexes formed will remain immobilized on the solid surface. The detection of complexes anchored on the solid surface can be accomplished in a number of ways. Where the previously non-immobilized component is pre-labeled, the detection of label immobilized on the surface indicates that complexes were formed. Where the previously non-immobilized component is not pre-labeled, an indirect label can be used to detect complexes anchored on the solid surface; e.g., using a labeled antibody specific for the previously non-immobilized component.

[0072] Alternatively, a reaction is conducted in a liquid phase, the reaction products separated from unreacted components using an immobilized antibody specific for CD38/SM38 protein, fusion protein or the test compound, and complexes detected using a labeled antibody specific for the other component of the possible complex to detect anchored complexes.

[0073] In accordance with the invention, non-cell based assays may also be used to screen for compounds that directly inhibit or activate enzymatic activities associated with CD38/SM38 . Such activities include but are not limited to ADP-ribosyl cyclase activity, transglycosidation activity, and NAD+ glycohydrolase activity. To this end, a reaction mixture of CD38/SM38 and a test compound is prepared in the presence of substrate and the enzymatic activity of CD38/SM38 is compared to the activity observed in the absence of test compound. Substrates that may be used in

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the assays for detection of CD38/SM38 enzyme activity include but are not limited to NAD+ and NADP and labeled forms thereof. Additionally, derivatives of NAD such as Nicotinamide guanine dinucleotide (NGD) and Nicotinamide 1, N^6-etheno-adenine dinucleotide (1,N^6 etheno-NAD) may be used.

[0074] In non-limiting embodiments of the invention, a reaction mixture of CD38/SM38 , a test compound and substrate is prepared and the activity of CD38/SM38 is compared to the activity observed in the absence of the test compound wherein decrease in the level of CD38/SM38 enzyme activity in the presence of the test compound indicates that a CD38/SM38 antagonist has been identified. Alternatively, a reaction mixture of CD38/SM38 , a test compound and substrate is prepared and the activity of CD38/SM38 is compared to the activity observed in the absence of the test compound wherein an increase in the level of CD38/SM38 enzyme activity in the presence of the test compound indicates that a CD38/SM38 agonist has been identified.

[0075] The enzymatic activity of CD38/SM38 may be detected in a variety of different ways. For example, levels of cyclic adenosine diphosphate ribose (cADPR) adenosine diphosphate ribose (ADPR) and/or nicotinic acid adenine dinucleotide phosphate (NAADP) can be measured using high performance liquid chromatography (HPLC) or thin layer chromatography (TLC) (Aarhus R et al., 1995, J. Biochem. Chem. 270:30327-30333; Muller-Steffner HM, J. Biol. Chem. 271:23967-23972; and Lund FE et al., 1999, *J. Immunology* 162:2693-2702; Higashida, H. et al., 1997, *J. Biol. Chem.* 272:3127-3177) in conjunction with the use of radio-labeled substrates such as NAD or NADP or NA. Additionally, radioimmunoassays (Takahashi K et al., 1995, *FEBS Lett* 371:204-208; Vu CQ

et al., 1997, *Biochem Biophys Res Commun* 236:723-726; Vu et al., *Adv Exp Med Biol* 419:381-388;

and Graeff RM et al., 1997, *Methods Enzymol* 280:230-241), bioassays (Aarhus R et al., 1995, *J. Biol Chem*. 270:30327-30333; Clapper DL et al., *J. Biol. Chem*. 262:9561-9568; and Lee et al., *J. Biol. Chem*. 264:1608-1615) and/or fluorescent assays (Graeff RM et al., 1996, *Biochem*. 35:379-386; Graeff et al., 1994, *J. Biol. Chem*. 269:30260-30267; and Gadangi P et al., 1996, *J. Immunol*. 156:1937-1941) may be used for measuring cADPR, ADPR or NAADP levels. In yet another embodiment of the invention, derivatives of NAD such as NGD (Nicotinamide guanine dinucleotide) and Nicotinamide 1, N^6-etheno-adenine dinucleotide (1,N^6 etheno-NAD) may be used to measure CD38/SM38 enzyme activity. When the 1,N^6 etheno-NAD is hydrolysed by CD38, one of the resulting products will fluoresce (Muller et al., 1983, *Biochem. J*. 212:459-464; and Cockayne D et al., 1998, *Blood* 92:1324-1333). When the analog NGD is cyclized through the ADP-ribosyl activity of CD38/SM38 the product forms a fluorescent compound that can be detected by fluorimeter (Graeff et al., 1996, *Biochem* 35:379-386; and Graeff et al., 1994, *J. Biol. Chem*. 269:30260-30267).

[0076] In another embodiment of the invention, computer modeling and searching technologies will permit identification of potential modulators of CD38/SM38 enzyme activity. For example, based on the knowledge of the Aplysia cyclase active site (Munshi C. et al., 199, J. Biol. Chem. 274: 30770-30777) and the CD38 active site (Lund FE et al., 1999, *J. Immunology* 162:2693-2702; Munshi, C et al., 2000, *J. Biol. Chem*. 275:21566-21571; Graeff R et al., 2001, J. Biol. Chem. 276:12169-12173) and the study of complexes between CD38/SM38 substrates and substrate anologs, potential modulators of CD38/SM38 activity may be identified.

[0077]   The three dimensional geometric structure of the active site may be determined using known methods, including x-ray crystallography, which can determine a complete molecular structure (see, for example, Prasad GS et al., *Nature Struc. Biol.* 3:957-964 which describes the crystal structure of Aplysia ADP ribosyl cyclase). On the other hand, solid or liquid phase NMR can be used to determine certain intramolecular distances. Any other experimental method of structure determination can be used to obtain the partial or complete geometric structure of the CD38 active site.

[0078]   Having determined the structure of the CD38/SM38 active site, candidate modulating compounds can be identified by searching databases containing compounds along with information on their molecular structure. Such a search seeks compounds having structures that match the determined active site structure and that interact with the groups defining the active site. Such a search can be manual, but is preferably computer assisted. These compounds found from this search are potential CD38 modulating compounds.

[0079]   Alternatively, these methods can be used to identify improved modulating compounds from an already known modulating compounds. For example, a number of compounds that modulate the enzyme activity of other enzymes that utilize NAD/NADP as substrates (*i.e.*, PARP family homologues) have already been identified. The composition of the known compound can be modified and the structural effects of modification can be determined using experimental and computer modeling methods applied to the new composition. The altered structure is then compared to the active site structure of the compound to determine if an improved fit or interaction results.

In this manner systematic variations in composition, such as by varying side groups, can be quickly evaluated to obtain modified modulating compounds or substrates of improved specificity or activity.

5. 2. 3.CELL BASED ASSAYS

[0080] In accordance with the invention, a cell based assay system can be used to screen for compounds that modulate the activity of CD38/SM38. In accordance with the invention, a cell-based assay system can be used to screen for compounds that modulate the activity of CD38 and thereby, modulate the chemoattractant induced Ca^{2+} influx and the migration of cells. Additionally, this cell based system can be used to screen for compounds that modulate the activity of SM38, and thereby, modulate intracellular calcium release and/or muscle contractility in cells. To this end, cells that endogenously express CD38/SM38 can be used to screen for compounds. Such cells include, for example, neutrophils, lymphocytes, eosinophils, macrophages and dendritic cells. In addition, _S. mansoni_ cells that express SM38, may be used to screen for compounds. Alternatively, cell lines, such as 293 cells, COS cells, CHO cells, fibroblasts, and the like, genetically engineered to express CD38/SM38 can be used for screening purposes. For screens utilizing host cells geneticlaly engineered to express a functional CD38 protein, it would be preferred to use host cells that are capable of responding to chemoattractants or inflammatory stimuli. For screens utilizing host cells geneticlaly engineered to exprss SM38, it would be preferable to use cells of _S. mansoni_ origin that are capable of responding to a variety fo stimuli such as acetylcholine or high concentrations of K+ to induce muscle contraction. Further, ooyctes or liposomes engineered to express the CD38/SM38

protein may be used in assays developed to identify modulators of CD38/SM38 activity.

[0081] The present invention provides methods for identifying compounds that alter one of more of the enzymatic activities of CD38/SM38 , including but not limited to, NAD glycohydrolase activity, ADP-ribosyl cyclase activity and/or transglycosidation (exchange) activity. Specifically, compounds may be identified that promote CD38/SM38 enzyme activities, *i.e.*, agonists, or compounds that inhibit CD38/SM38 enzyme activities, *i.e.*, antagonists. Compounds that inhibit CD38 enzyme activities will be inhibitory for chemoattractant induced calcium responses and cell migration (Figure 2). Compounds that activate CD38 enzyme activity will enhance chemoattractant induced calcium responses and cell migration. Compounds that either activate or inhibit SM38 enzyme activities will alter the viability or functional activities of pathogenic organisms expressing SM38. Such compounds may be compounds that interact with the active site of CD38/SM38 thereby modulating enzyme activity, or compounds that compete/facilitate substrate binding to CD38/SM38 or compete/inhibit catalysis of substrate (Figure 2). Alternatively, compounds may be identified that modulate the activity of proteins that modify the CD38/SM38 protein, *i.e.*, phosphorylate, ribosylate, etc., and thereby regulate the activity of CD38 (Figure 3). Such proteins include for example, ADP-ribosyl transferases which ribosylate CD38/SM38 and render CD38/SM38 enzymatically inactive. In addition, compounds may be identified that regulate CD38/SM38 expression and thereby regulate the level of enzyme activity within a cell (Figure 4).

[0082] The present invention provides for methods for identifying a compound that activates CD38/SM38 enzyme activity comprising (i) contacting a cell expressing CD38/SM38 and

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chemoattractant receptors with a test compound in the presence of substrate and measuring the level

of CD38/SM38 activity; (ii) in a separate experiment, contacting a cell expressing CD38/SM38

protein and chemoattractant receptors with a vehicle control in the presence of substrate and

measuring the level of CD38/SM38 activity where the conditions are essentially the same as in part

(i), and then (iii) comparing the level of CD38/SM38 activity measured in part (i) with the level of

CD38/SM38 activity in part (ii), wherein an increased level of CD38/SM38 activity in the presence

of the test compound indicates that the test compound is a CD38/SM38 activator.

[0083]   The present invention also provides for methods for identifying a compound that inhibits

CD38/SM38 enzyme activity comprising (i) contacting a cell expressing CD38/SM38 and

chemoattractant receptors with a test compound in the presence of a chemoattractant and substrate

and measuring the level of CD38/SM38 activity; (ii) in a separate experiment, contacting a cell

expressing CD38/SM38 and chemoattractant receptors with a chemoattractant and substrate and

measuring the level of CD38/SM38 activity, where the conditions are essentially the same as in part

(i) and then (iii) comparing the level of CD38/SM38 activity measured in part (i) with the level of

CD38/SM38 activity in part (ii), wherein a decrease level of CD38/SM38 activity in the presence

of the test compound indicates that the test compound is a CD38/SM38 inhibitor.

[0084]   Depending on the assays used to detect CD38/SM38 activity, the methods described above

for identifying activators and inhibitors of CD38/SM38 may include the presence or absence of a

chemoattractant in steps (i) and (ii). For example, when assaying directly for CD38/SM38 ADP-

ribosyl cyclase activity or the production of CD38/SM38 metabolites, the presence of a

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chemoattractant or the expression of a chemoattractiant receptor on the test cell may not be required. However, in instances where, for example, chemotaxis or changes in intracellular calcium levels are measured in CD-38-expressing cells it may be necessary to include chemoattractants. Alternatively, when muscle contractility or changes in intracellular calcium levels are measured in SM38-expressing cells, it may be necessary to include stimulants to activate muscle contraction and/or calcium release including, but not limited to, acetylcholine, serotonin (Day et al., 1994, Paristol. 108:425-432), FMRF-amide related peptides (FaRPs) (Day et al., 1994, Paristol. 109:455-459) or high K+ concentrations in the media (Day et al., 1993, Paristol. 106:471-477). Additionally, it will be necessary to perform these experiments with host cells that express the receptors specific for the stimulants utilized. Those skilled in the art will be able to determine operative and optimal assay conditions by employing routine experimentation.

[0085] A "chemoattractant", as defined herein, is a compound or molecular complex that induces the migration of cells via a mechanism that is dependent on the production of cADPR by CD38. An example of such a chemoattractant includes, but is not limited to, fMet-leu-Phe (fMLP). Other chemoattractants that may be used include, eotaxin, GRO-1, IP-10, SDF-1, BLC, Rantes, MIP-1A, MCP-3, MIP3a, IL-8, CLS, ELC, Lymphotactin, PAF, Ltb4, complement c5a and histamine.

[0086] In utilizing the cell systems described above, such cell systems, the cells expressing the CD38/SM38 protein are exposed to a test compound or to vehicle controls (e.g., placebos). After exposure, the cells can be assayed to measure the activity of CD38/SM38 or the activity of the CD38 dependent signal transduction pathway itself can be assayed.

[0087]   The ability of a test molecule to modulate the activity of CD38/SM38 may be measured using standard biochemical and physiological techniques.   Responses such as activation or suppression of CD38/SM38 ADP-ribosyl cyclase activity or   the production of CD38/SM38 metabolites such as cADPR and/or NAADP can be measured.   Levels of cADPR, ADPR and/or NAADP can be measured using HPLC or TLC in conjunction with the use of radio-labeled substrates such as NAD or NADP or NA.   Additionally, radioimmunoassays, bioassays and/or fluorescent assays, such as those discussed in Section 5.1.1, *supra*, may be used for measuring cADPR or NAADP levels. In yet another embodiment of the invention, derivatives of NAD such as NGD (Nicotinamide guanine dinucleotide) and Nicotinamide 1, N^6-etheno-adenine dinucleotide $(1,N^6$ etheno-NAD) may be used to measure CD38/SM38 activity.

[0088]   Test compounds may also be assayed utilizing cell based calcium and/or migration assays to identify compounds that are capable of inhibiting or activating chemoattractant induced CD38 dependent calcium responses and cell migration. In non-limiting embodiments of the invention, changes in intracellular Ca^{2+} levels may be monitored by the fluorescence of Ca^{2+} indicator dyes such as Indo, Fluo-3 and Fura-Red, etc. Further, changes in membrane potential resulting from modulation of the CD38/SM38 enzyme activity can be measured using a voltage clamp or patch recording methods. Directed migration of cells may also be monitored by standard chemotaxis assays in modified Boyden chambers or on slides. Such assay systems are described in further detail in the working example of the present specification (See, Example 6). Muscle contractility may also be measured by standard assays described in detail in the literature (for example: (Day et al., 1994

Parasitology 109:455-9) and references therein).

[0089]   After exposure to the test compound, or in the presence of a test compound, cells can be stimulated with a chemoattractant such as fMLP or a muscle activator such as high K+ concentrations, and changes in intracellular calcium levels, cADPR or NAADP levels, muscle contractility and/or cell migration may be measured. These measurements will be compared to cells treated with the vehicle control. Increased levels of intracellular Ca^{2+}, increased production of cADPR, increases in muscle contractility and/or increased migration of cells toward a chemoattractant in the presence of a test compound indicates that the compound acts as an agonists to increase the Ca2+ response increase muscle contractility and increase chemoattractant induced CD38 dependent cell migration. Decreased levels of intracellular Ca2+, decreased production of cADPR, decreased muscle contractility and/or decreased migration of cells toward a chemoattractant in the presence of a test compound indicates that the compound acts as an antagonist and inhibits the Ca2+ response, decreases muscle contractility and inhibits chemoattractant induced CD38 dependent cell migration (see, for example, Figures 2 and 3).

[0090]   In addition, the assays of the invention may be used to identify compounds that (i) function as substrates of CD38/SM38 enzymatic activity and are converted into agonists or antagonists of cADPR dependent Ca2+ signal transduction pathway (Figure 5). A compond fitting these specifications is described in further detail in the working exmaple of the present specification (Example 6, Figure 11). Alternatively, the assays of the invention may be used (ii) to identify compounds that specifically interfere with the cADPR mediated Ca2+ signal transduction pathways

(Figure 6). In a non-limiting embodiment of the invention, test compounds may include chemical derivatives of any known and unknown substrates of CD38/SM38 (for example, the substrate analog 8-Br-βNAD is converted into the modified product 8-Br-cADPR which acts as an antagonist of cADPR mediated Ca2+ signal transduction). The test substrate may be administered to cells expressing CD38/SM38 and the appropriate chemoattractant receptors in the presence of the chemoattractant or muscle stimulant. Conversion of the modified test substrate into a modified product that is capable of modulating the activity of cADPR can be measured utilizing the methods described above. Test substrates may also be assayed to determine their effect on calcium influx, muscle contractility and/or cell migration. Intracellular Ca2+ accumulation and directed migration to a chemoattractant can be measured in cells treated with the test substrate and the chemoattractant and compared to cells receiving the non-modified substrate. *i.e.*, NAD and a chemoattractant. Compounds which are converted into modified products, *i.e.*, 8-Br-cADPR, and competitively or non-competitively inhibit cADPR induced calcium responses, muscle contractility or directed migration will be identified as antagonists of the cADPR Ca^{2+} signaling pathway, while compounds that are converted into modified products that are competitive or non-competitive agonists of the cADPR Ca^{2+} signaling pathway will be defined as agonists or activators.

[0091] In yet another embodiment of the invention, compounds that directly alter (*i.e.*, activate or inactivate) the activity of cADPR, *i.e.*, induced calcium release and cell migration, can be tested in assays. Such agonists or antagonists would be expected to modulate the influx of Ca2+ into the cell resulting in changes in the cell's migratory activity or ability to contract. Antagonists would have

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reduced Ca2+ responses, reduced contractility and/or reduced migration in the presence of a chemoattractant. Examples of antagonists include, but are not limited to 8-NH$_2$-cADPR, 8-Br-cADPR, 8-CH$_3$-cADPR, 8-OCH$_3$-cADPR and 7-Deaza-8-Br-cADPR. A compound fitting these specifications is described in further detail in the working example of the present specification (Example 6, Figure 10).Agonists would have increased Ca2+ responses, increased contractility and/or increased migration in the presence of chemoattractants. Examples of agonists include but are not limited to 2'-deoxy-cADPR, 3'-deoxy-cADPR and 2'-phospho-cADPR. Assays for direct measurement of cAPDR activity include the bioassays such as those described by Howard et al. (1995, Science 262:1056); Galione et al. (1993, Nature 365:456-459) and Lee and Aarhus (1991, Cell Regulation 2:203-209).

[0092] Further, the assays of invention may identify compounds that are capable of activating CD38/SM38 enzyme activity, *i.e.*, agonists, but which desensitize the calcium pathway by depletion of intracellular calcium stores. Such desensitization may, in some instances, lead to inhibition of cell migration or muscle contraction due to the depletion of calcium stores. Thus compounds may be identified that function as agonists in CD38/SM38 enzyme assays but function as antagonists in chemotaxis or muscle contraction assays. Such assays and compounds are within the scope of the present invention.

5.2.4. ASSAY FOR COMPOUNDS THAT REGULATE THE EXPRESSION OF CD38/SM38

[0093] In accordance with the invention, a cell based assay system can be used to screen for

compounds that modulate the expression of CD38/SM38 within a cell. Assays may be designed to screen for compounds that regulate CD38/SM38 expression at either the transcriptional or translational level. In one embodiment, DNA encoding a reporter molecule can be linked to a regulatory element of the CD38/SM38 gene and used in appropriate intact cells, cell extracts or lysates to identify compounds that modulate CD38/SM38 gene expression. Such reporter genes may include but are not limited to chloramphenicol acetyltransferase (CAT), luciferase, β-glucuronidase (GUS), growth hormone, or placental alkaline phosphatase (SEAP). Such constructs are introduced into cells thereby providing a recombinant cell useful for screening assays designed to identify modulators of CD38/SM38 gene expression.

[0094] Following exposure of the cells to the test compound, the level of reporter gene expression may be quantitated to determine the test compound's ability to regulate CD38/SM38 expression. Alkaline phosphatase assays are particularly useful in the practice of the invention as the enzyme is secreted from the cell. Therefore, tissue culture supernatant may be assayed for secreted alkaline phosphatase. In addition, alkaline phosphatase activity may be measured by calorimetric, bioluminescent or chemiluminescent assays such as those described in Bronstein, I. et al. (1994, *Biotechniques* 17: 172-177). Such assays provide a simple, sensitive easily automatable detection system for pharmaceutical screening.

[0095] To identify compounds that regulate CD38/SM38 translation, cells or *in vitro* cell lysates containing CD38/SM38 transcripts may be tested for modulation of CD38/SM38 mRNA translation. To assay for inhibitors of CD38/SM38 translation, test compounds are assayed for their ability to

modulate the translation of CD38/SM38 mRNA in *in vitro* translation extracts.

[0096]   In an embodiment of the invention, the level of CD38/SM38 expression can be modulated using antisense or ribozyme approaches to inhibit or prevent translation of CD38/SM38 mRNA transcripts or triple helix approaches to inhibit transcription of the CD38/SM38 gene.   Such approaches may be utilized to treat disorders such as inflamation and allergies where inhibition of CD38/SM38 expression is designed to prevent hematopoietically-derived cell migration or inhibition of SM38 is designed to alter *S. mansoni* physiology and pathogenesis.

[0097]   Antisense approaches involve the design of oligonucleotides (either DNA or RNA) that are complementary to CD38/SM38 mRNA.   The antisense oligonucleotides will bind to the complementary mRNA transcripts and prevent translation.   Absolute complementarity, although preferred, is not required.   One skilled in the art can ascertain a tolerable degree of mismatch by use of standard procedures to determine the melting point of the hybridized complex.

[0098]   In yet another embodiment of the invention, ribozyme molecules designed to catalytically cleave CD38/SM38 mRNA transcripts can also be used to prevent translation of CD38/SM38 mRNA and expression of CD38/SM38.   (See, e.g., PCT International Publication WO90/11364, published October 4, 1990; Sarver et al., 1990, Science 247:1222-1225).   Alternatively, endogenous CD38/SM38 gene expression can be reduced by targeting deoxyribonucleotide sequences complementary to the regulatory region of the CD38/SM38 gene (*i.e.*, the CD38 promoter and or enhancers) to form triple helical structures that prevent transcription of the CD38/SM38 gene in

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targeted hematopoietically-derived cells in the body. (See generally, Helene, C. et al., 1991, Anticancer Drug Des. 6:569-584 and Maher, LJ, 1992, Bioassays 14:807-815).

[0099]   The oligonucleotides of the invention, i.e., antisense, ribozyme and triple helix forming oligonucleotides, may be synthesized by standard methods known in the art, e.g., by use of an automated DNA synthesizer (such as are commercially available from Biosearch, Applied Biosystems, etc.). Alternatively, recombinant expression vectors may be constructed to direct the expression of the oligonucleotides of the invention. Such vectors can be constructed by recombinant DNA technology methods standard in the art. In a specific embodiment, vectors such as viral vectors may be designed for gene therapy applications where the goal is in vivo expression of inhibitory oligonucleotides in targeted cells.

5.2.5. COMPOUNDS THAT CAN BE SCREENED IN ACCORDANCE WITH THE INVENTION

[0100] The assays described above can identify compounds which modulate CD38/SM38 activity. For example, compounds that affect CD38/SM38 activity include but are not limited to compounds that bind to CD38/SM38 , and either activate enzyme activities (agonists) or block enzyme activities (antagonists). Alternatively, compounds may be identified that do not bind directly to CD38/SM38 but are capable of altering CD38/SM38 enzyme activity by altering the activity of a protein that regulates CD38 enzyme activity (see, Figure 3) Compounds that are substrates of CD38 that are converted into modified products that activate or inhibit the cADPR Ca2+ signal transduction pathway can also be identified by the screens of the invention.

Compounds that directly activate or inhibit the cADPR Ca2+ signal transduction pathway in cells can also be identified. Additionally, compounds that activate CD38/SM38 enzyme activity resulting in desensitization of the calcium pathway may be identified. Such desensitizing compounds would be expected to inhibit cell migration. Further, compounds that affect CD38/SM38 gene activity (by affecting CD38/SM38 gene expression, including molecules, e.g., proteins or small organic molecules, that affect transcription or interfere with splicing events so that expression of the full length or the truncated form of the CD38/SM38 can be modulated) can be identified using the screens of the invention.

[0101] The compounds which may be screened in accordance with the invention include, but are not limited to, small organic or inorganic compounds, peptides, antibodies and fragments thereof, and other organic compounds (e.g., peptidomimetics) that bind to CD38/SM38 and either mimic the activity triggered by any of the known or unknown substrates of CD38/SM38 (*i.e.*, agonists) or inhibit the activity triggered by any of the known or unknown substrates of CD38/SM38 (*i.e.*, antagonists). Compounds that bind to CD38/SM38 and either enhance CD38/SM38 enzyme activities (*i.e.*, ADP-ribosyl cyclase activity, NAD glycohydrolase activity, transglycosidation activity), *i.e.*, agonists, or compounds that inhibit CD38/SM38 enzyme activities, i.e., antagonists, in the presence or absence of the chemoattractant or muscle stimulant will be identified. Compounds that bind to proteins that alter/modulate the enzyme activity of CD38/SM38 will be identified. Compounds that mimic natural substrates , i.e., NAD(P) and are converted by CD38/SM38 enzyme activities into products that act as agonists or antagonists of

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the cADPR induced calcium release pathway can be identified. Compounds that directly activate or inhibit the cADPR Ca2+ signal transduction pathway in cells can be identified.

[0102] Compounds may include, but are not limited to, peptides such as, for example, soluble peptides, including but not limited to members of random peptide libraries (see, e.g., Lam, K.S. et al., 1991, Nature 354:82-84; Houghten, R. et al., 1991, Nature 354:84-86); and combinatorial chemistry-derived molecular library made of D- and/or L- configuration amino acids, phosphopeptides (including, but not limited to, members of random or partially degenerate, directed phosphopeptide libraries; (see, e.g., Songyang, Z. et al., 1993, Cell 72:767-778), antibodies (including, but not limited to, polyclonal, monoclonal, humanized, anti-idiotypic, chimeric or single chain antibodies, and FAb, F(ab')$_2$ and FAb expression library fragments, and epitope binding fragments thereof), and small organic or inorganic molecules.

[0103] Other compounds which may be screened in accordance with the invention include but are not limited to small organic molecules that affect the expression of the CD38/SM38 gene or some other gene involved in the CD38/SM38 signal transduction pathway (e.g., by interacting with the regulatory region or transcription factors involved in gene expression); or such compounds that affect the enzyme activities of the CD38/SM38 or the activity of some other factor involved in modulating CD38/SM38 enzyme activity, such as for example, a protein that ribosylates CD38/SM38 and thereby inactivates CD38/SM38 enzyme activities.

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5.3. COMPOSITIONS CONTAINING MODULATORS
OF CD38/SM38 AND THEIR USES

[0104] The present invention provides for methods of modulating cell migration comprising contacting a cell expressing CD38 with an effective amount of a CD38 modulating compound, such as a CD38 agonist or antagonist identified using the assays as set forth in Section 5.1 *supra*. Additionally, the present invention provides for methods of modulating calcium responses and/or muscle contractility comprising contacting a cell expressing SM38 with an effective amount of a SM38 modulating compound, such as a SM38 agonist or antagonist identified using the assays as set forth in Section 5.1 *supra*. An "effective amount" of the CD38/SM38 inhibitor, *i.e.*, antagonist, is an amount that decreases chemoattractant induced cell migration decreases intracellular calcium levels, decreases muscle contraction and/or that is associated with a detectable decrease in CD38/SM38 enzyme activity as measured by one of the above assays. An "effective amount" of the CD38/SM38 activator, *i.e.*, agonist, is an amount that subjectively increases chemoattractant induced cell migration, increases intracellular calcium levels, increases muscle contraction and/or that is associated with a detectable increase in CD38/SM38 enzyme activity as measured by one of the above assays. Compositions of the invention also include modified CD38/SM38 substrates, modulators of CD38/SM38 expression and agonists/antagonists of cADPR.

[0105] The present invention further provides methods of modulating cell migration in a subject, comprising administering to the subject, a composition comprising a compound that modulates CD38 enzyme activity identified as set forth in Section 5.1 *supra*. The composition may

comprise an amount of CD38 enzyme activator or inhibitor, modulators of CD38 expression, modified CD38 substrates, or direct agonists/antagonists of cADPR controlled Ca2+ responses. Accordingly, the present invention provides for compositions comprising CD38 activators and inhibitors.

[0106] The present invention provides for compositions comprising an effective amount of a compound capable of modulating the activity of CD38, the expression of CD38 and/or the activity of cADPR thereby regulating the migratory activity of cells, and a pharmaceutically acceptable carrier. In a specific embodiment, the term "pharmaceutically acceptable" means approved by a regulatory agency of the Federal or a state government or listed in the U.S. Pharmacopeia or other generally recognized pharmacopeia for use in animals, and more particularly in humans. The term "carrier" refers to a diluent, adjuvant, excipient, or vehicle with which the therapeutic is administered. Examples of suitable pharmaceutical carriers are described in "Remington's Pharmaceutical sciences" by E.W. Martin.

[0107] The invention provides for treatment or prevention of various diseases and disorders associated with cell migration by administration of a compound that regulates the expression or activity of CD38. Such compounds include but are not limited to CD38 antibodies; CD38 antisense nucleic acids, CD38 agonists and antagonists (see, Figures 2-3), modified CD38 substrates (see, Figure 5) and cADPR agonists and antagonists (see, Figure 6). In a non-limiting embodiment of the invention, disorders associated with hematopoietic derived cell migration are treated or prevented by administration of a compound that regulates CD38 activity. Such

disorders include but are not limited to inflammation, ischemia, asthma, auto-immune disease, diabetes, allergies, infections, arthritis and organ transplant rejections.

[0108] The compounds of the invention are preferably tested *in vitro*, and then *in vivo* for a desired therapeutic or prophylactic activity, prior to use in humans. For example, *in vitro* assays which can be used to determine whether administration of a specific therapeutic is indicated, include *in vitro* cell culture assays in which cells expressing CD38 are exposed to or otherwise administered a therapeutic compound and the effect of such a therapeutic upon CD38 activity is observed. In a specific embodiment of the invention the ability of a compound to regulate, *i.e.*, activate or inhibit cell migration may be assayed.

[0109] The present invention further provides methods of modulating the muscle contraction or other physiologic parameters in helminths such as *S. mansoni* by administering to helminth infected subject, a composition comprising a compound that modulates SM38 enzyme activity identified as set forth in Section 5.1 *supra*. The composition may comprise an amount of SM38 enzyme activator or inhibitor, modulators of SM38 expression, modified SM38 substrates, or direct agonists/antagonists of cADPR controlled Ca2+ responses. Accordingly, the present invention provides for compositions comprising SM38 activators and inhibitors.

[0110] The present invention provides for compositions comprising an effective amount of a compound capable of modulating the activity of SM38, the expression of SM38 and/or the

activity of cADPR thereby regulating the activity and viability of the parasite, and a pharmaceutically acceptable carrier. In a specific embodiment, the term "pharmaceutically acceptable" means approved by a regulatory agency of the Federal or a state government or listed in the U.S. Pharmacopeia or other generally recognized pharmacopeia for use in animals, and more particularly in humans. The term "carrier" refers to a diluent, adjuvant, excipient, or vehicle with which the therapeutic is administered. Examples of suitable pharmaceutical carriers are described in "Remington's Pharmaceutical sciences" by E.W. Martin.

[0111] The invention provides for treatment or prevention of various diseases and disorders associated with helminth infections. Such compounds include but are not limited to SM38 antibodies; SM38 antisense nucleic acids, SM38 agonists and antagonists (see, Figures 2-3), modified SM38 substrates (see, Figure 5) and cADPR agonists and antagonists (see, Figure 6). In a non-limiting embodiment of the invention, disorders associated with helminth infection are treated or prevented by administration of a compound that regulates SM38 activity. Such disorders include but are not limited to granuloma formation and fibrosis in the liver and lung.

[0112] The compounds of the invention are preferably tested *in vitro*, and then *in vivo* for a desired therapeutic or prophylactic activity, prior to use in humans. For example, *in vitro* assays which can be used to determine whether administration of a specific therapeutic is indicated, include *in vitro* cell culture assays in which cells expressing SM38 are exposed to or otherwise administered a therapeutic compound and the effect of such a therapeutic upon SM38 activity is observed. In a specific embodiment of the invention the ability of a compound to regulate, *i.e.*,

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activate or inhibit muscle contractility or intracellular calcium accumulation. Additionally, the compounds of the invention may be assayed for their effect on *S. mansoni* pathogenesis, growth, differentiation, and reproduction in a mouse model for *S. mansoni* infection. Such assays would include the testing for effects on proliferation of parasites, maturation of female worms, quantity of granulomas in liver and lung, quantity of eggs in liver, lung bladder and intestines , quatity of worms in lung and liver and quantity of miracidia detected in urine and feces.

[0113] Additionally, the compounds of the invention may be assayed for their effect on *S. mansoni* pathogenesis, growth, differentiation, and reproduction. Such compounds could be tested in a mouse model for *S. mansoni* infection. Such assays would include the testing for effects on proliferation of parasites, quantity of granulomas in liver and lung, quantity of eggs in liver, lung bladder and intestines and quantity of miracidia detected in urine and feces.

[0114] The invention provides methods of treatment and/or prophylaxis by administration to a subject of an effective amount of a compound of the invention. In a preferred aspect, the compound is substantially purified. The subject is preferably an animal, and is preferably a mammal, and most preferably human.

[0115] Various delivery systems are known and can be used to administer a compound capable of regulating CD38 activity, cADPR, or CD38 expression, *e.g.*, encapsulation in liposomes, microparticles, microcapsules, recombinant cells capable of expressing the compound, receptor-mediated endocytosis (see, e.g., Wu and Wu, 1987, *J. Biol. Chem.* 262:4429-4432). Methods of

introduction include but are not limited to intradermal, intramuscular, intraperitoneal, intravenous, subcutaneous, intranasal, epidural, and oral routes. The compounds may be administered by any convenient route, for example by infusion or bolus injection, by absorption through epithelial or mucocutaneous linings (e.g., oral mucosa, rectal and intestinal mucosa, etc.) and may be administered together with other biologically active agents. Administration can be systemic or local. Pulmonary administration can also be employed, *e.g.*, by use of an inhaler or nebulizer, and formulation with an aerosolizing agent.

[0116] In a specific embodiment, it may be desirable to administer the compositions of the invention locally to a specific area of the body; this may be achieved by, for example, and not by way of limitation, local infusion during surgery, topical application, e.g., in conjunction with a wound dressing after surgery, by injection, by means of a catheter, by means of a suppository, or by means of an implant, said implant being of a porous, non-porous, or gelatinous material, including membranes, such as sialastic membranes, or fibers.

[0117] The present invention also provides pharmaceutical compositions. Such compositions comprise a therapeutically effective amount of a compound capable of regulating CD38 activity, cADPR activity or CD38 expression and a pharmaceutically acceptable carrier. In a specific embodiment, the term "pharmaceutically acceptable" means approved by a regulatory agency of the Federal or a state government or listed in the U.S. Pharmacopeia or other Generally recognized pharmacopeia for use in animals, and more particularly in humans. The term "carrier" refers to a diluent, adjuvant, excipient, or vehicle with which the therapeutic is

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administered. Such pharmaceutical carriers can be sterile liquids, such as water and oils,

including those of petroleum, animal, vegetable or synthetic origin, such as peanut oil, soybean

oil, mineral oil, sesame oil and the like. Water is a preferred carrier when the pharmaceutical

composition is administered intravenously. Saline solutions and aqueous dextrose and glycerol

solutions can also be employed as liquid carriers, particularly for injectable solutions. The

composition can be formulated as a suppository, with traditional binders and carriers such as

triglycerides. Oral formulation can include standard carriers such as pharmaceutical grades of

mannitol, lactose, starch, magnesium stearate, sodium saccharine, cellulose, magnesium

carbonate, etc. Examples of suitable pharmaceutical carriers are described in "Remington's

Pharmaceutical sciences" by E.W. Martin. Such compositions will contain a therapeutically

effective amount of the therapeutic compound, preferably in purified form, together with a

suitable amount of carrier so as to provide the form for proper administration to the patient. The

formulation should suit the mode of administration.

[0118] The amount of the compound of the invention which will be effective in the treatment of

a particular disorder or condition will depend on the nature of the disorder or condition, and can

be determined by standard clinical techniques. In addition, *in vitro* assays may optionally be

employed to help identify optimal dosage ranges. The precise dose to be employed in the

formulation will also depend on the route of administration, and the seriousness of the disease or

disorder, and should be decided according to the judgment of the practitioner and each patient's

circumstances. Effective doses may be extrapolated from dose response curves derived from

in vitro or animal model test systems. Additionally, the administration of the compound could be combined with other known efficacious drugs if the *in vitro* and *in vivo* studies indicate a synergistic or additive therapeutic effect when administered in combination.

[0119] The invention also provides a pharmaceutical pack or kit comprising one or more containers filled with one or more of the ingredients of the pharmaceutical compositions of the invention, optionally associated with such container(s) can be a notice in the form prescribed by a governmental agency regulating the manufacture, use or sale of pharmaceuticals or biological products, which notice reflects approval by the agency of manufacture, use or sale for human administration.

6. EXAMPLE: NEUTROPHILS REQUIRE CD38 FOR CHEMOTAXIS, CAPACITATIVE Ca+ ENTRY AND BACTERIAL CLEARANCE

[0120] The subsection below describes data demonstrating that calcium entry in chemoattractant activated neutrophils is controlled by cADPR, a product of the CD38 enzyme reaction. The capacitative calcium influx, controlled by the cADPR produced by CD38, is required for neutrophils to migrate efficiently to chemoattractants.

6.1. MATERIALS AND METHODS

6.1.1. MICE

[0121] C57BL/6J x 129 CD38KO F2 animals(Cockayne et al., 1998 *Blood* 92:1324-1333) were backcrossed 6 generations (N6) to C57BL/6J and then inbred to produce homozygous congenic

C57BL/6J.129 CD38KO mice. CD38-Rag-2 double KO (dKO) mice were produced by crossing

C57BL/6J.129 (N6) CD38KO mice with C57BL/6J.129 (N8) Rag-2 KO mice (Shin Kai et al.,

1992 *Cell* 68:855-867) and then mating the offspring to obtain homozygous double KO animals.

Bone marrow chimeric mice were produced by transplanting 1×10^7 whole bone marrow cells

isolated from WT or CD38KO mice into lethally irradiated (950 rad) WT hosts. All mice were

bred and maintained in the Trudeau Institute Animal Breeding Facility.

6.1.2.   cADPR CONTENT MEASUREMENTS.

[0122] Mouse tissues were isolated from whole-body perfused WT or CD38KO mice and were

flash frozen in liquid nitrogen. Bone marrow myeloid cells were flushed from the tibias and

femurs of Rag-2KO or Rag-2-CD38 dKO mice. cADPR content in mouse tissues and bone

marrow myeloid cells was then measured as previously described (Vu et al., 1997 *Biochem*

Biophys Res Commun 236:723-726).

[0123] S. pneumoniae infection. Mice were infected intra-tracheally with 100 or 1000 CFU S.

pneumoniae type 4 (Klein Strain) from American Type Tissue Culture (Rockville, Maryland).

Blood, bronchial-aveolar lavage fluid (BAL) and lung tissue were collected from infected mice

(Garvy et al., 1996 *Inflammation* 20:499-512). Bacterial titers in lung homogenate and blood

were calculated on a per lung basis or per ml of blood. BAL cells were enumerated from cyto-

centrifuge preparations.

6.1.3.   *IN VITRO* CHEMOTAXIS ASSAYS

[0124] Bone marrow neutrophils were purified (95% purity) by positive selection using

biotinylated GR-1 (PharMingen) and MACS Streptavidin Microbeads (Miltenyi Biotec, Auburn

CA). Chemotaxis assays(Falk et al., 1980 *J. Immuno. Methods* 33:239-247) were performed

using 24-well transwell plates with a 3 μm pore size polycarbonate filter (Costar, Cambridge,

MA). Medium (HBSS+Ca2$^+$+Mg2$^+$), fMLP (1 μM, Sigma, St. Louis, MO), or IL-8 (100 nM,

Sigma) was placed in the lower and/or upper chamber in a checkerboard format. 1x10^5

neutrophils were loaded in the upper chamber and the plates were incubated at 37° C for 45 min.

The transmigrated cells were collected from the lower chamber, fixed and counted on the flow

cytometer (FACS Calibur, Becton Dickinson, San Jose CA). To determine the absolute number

of cells in each sample, a standard number of 20 μM size fluorescent microspheres

(Polysciences, Inc. Warrington, PA) was added to each tube and counted along with the cells.

The total number of transmigrated cells = the number of counted neutrophils X total number of

beads/beads counted. In some experiments, neutrophils were incubated in EGTA (2mM) or pre-

treated for 20 min with 8-Br-cADPR (25-100 μM, Sigma) or N(8-Br-A)D+ (1.0 mM).

6.1.4.   CD38 EXPRESSION

[0125] Bone marrow, blood or peritoneal cavity cells were isolated from WT or CD38KO mice

and stained with anti-mouse GR-1 FITC, anti-mouse MAC-1 PE and anti-mouse CD38 APC

(PharMingen, San Diego CA). Human peripheral blood neutrophils were isolated on a ficoll

gradient and then stained with anti-hCD15-FITC (Becton Dickinson, San Jose CA) and anti-

hCD38-Biotin (Caltag Laboratories, Burlingame CA). Mouse and human neutrophils were

analyzed by flow cytometry, gating on the MAC-1^+GR-1^+ for mouse neutrophils and CD15$^+$ for

human neutrophils. To induce an inflammatory response, mice were injected with 1 ml 3%

thioglycollate medium intra-peritoneally (Becton Dickinson, Cockeysville MD). The animals

were sacrificed 12 hrs post-injection, and the cells infiltrating the peritoneal cavity were

collected.

6.1.4.   MEASUREMENT OF CD38 CYCLASE ACTIVITY

[0126] Measurement of CD38 cyclase activity. 1×10^6 purified bone marrow neutrophils were

incubated for 20 min at 37° C in 100 µl HBSS in a 96 well microplate. NGD (40 µM) (Sigma)

was added and the enzymatic conversion of NGD$^+$ to cGDPR was measured fluorometrically

(Graeff et al., 1994 *J. biol. Chem.* 269:30260-30267) over the next 10 minutes (415 nm emission

and 300 nm excitation).

6.1.5. RYR-3 MRNA EXPRESSION IN NEUTROPHILS

[0127] cDNA was prepared from RNA isolated from purified bone marrow neutrophils or brain

tissue. 30 cycles (annealing temperature 61°C) RT-PCR was performed with 0.03-2 µg input

cDNA and RyR-3 specific primers (Guse et al., 1999 *Nature* 398:70-73).

[0128] Synthesis of N(8-Br-A)D$^+$. N(8-Br-A)D$^+$ was synthesized as previously described

(Abdallah et al. 1975 *Eur. J Biochem* 50:475-481).

6.1.6.   INTRACELLULAR CALCIUM MEASUREMENTS

[0129] Purified bone marrow neutrophils were resuspended in cell loading media (HBSS with

$Ca2^+$ and $Mg2^+$ + 1% FBS + 4 mM probenecid) at 1×10^7 cells/ml. The cells were incubated at

37° C for 30 min with the fluorescent dyes Fluo-3 AM (4 µg/ml) and Fura Red AM (10 µg/ml)

(Molecular Probes, Eugene OR) and then washed twice and resuspended in cell loading medium

or calcium-free medium at 1×10^6 cells/ml. In some experiments, cells were permeabilized in 5

µM digitonin in calcium-free media. In other experiments, cells were preincubated with EGTA

(2mM), 8-Br-cADPR (10-100 µM), ruthenium red (Sigma) or $N(8\text{-Br-A})D^+$ (1mM) and then

stimulated with the carrier control (DMSO 0.01%), fMLP (1 µM), IL-8 (100 nM), ryanodine (1

µM), cADPR (100 µM) or thapsigargin (1 µM). The accumulation of $[Ca^2+]i$ in individual cells

was assessed by flow cytometry measuring the fluorescence emission of Fluo-3 in the FL-1

channel and Fura-Red in the FL-3 channel. Data was analyzed using FlowJo 3.2 (Tree Star, Inc.

San Carlos, CA). The relative $[Ca2^+]i$ was expressed as the ratio between Fluo-3 and Fura Red

mean fluorescence intensity over time.

6.2. RESULTS

[0130] CD38 is the primary ADP-ribosyl cyclase expressed in lymphoid tissues. To directly test

the requirement for CD38 and cADPR in calcium-sensitive immunologic responses *in vivo*,

CD38 knockout (CD38KO) mice where generated (Cockkayne et al. 1998 *Blood* 92:1324-1333).

To determine whether CD38 is the primary cyclase expressed in mice, the cADPR content in

tissues and cells isolated from CD38KO and C57BL/6J wild-type (WT) mice were

compared(Table 1).

Table 1. Comparison of cADPR content in tissues isolated from CD38KO and WT animals.

Tissue	cADPR content WT tissue (pmol/mg protein)	cADPR content CD38KO tissue (pmol/mg protein)
Spleen	2.108 ± 0.334	0.298 ± 0.091*
Thymus	0.769 ± 0.182	0.335 ± 0.088**
BM myeloid	0.633 ± 0.111	0.257 ± 0.032*
Lung	0.847 ± 0.213	0.480 ± 0.069
Kidney	0.488 ± 0.119	0.418 ± 0.070
Heart	1.249 ± 0.324	1.014 ± 0.237
Brain	3.865 ± 0.866	3.127 ± 0.316

Extracts were prepared from tissues isolated from 8-12 wk old CD38KO or WT mice or from bone marrow (BM) myeloid cells isolated from Rag-2KO or Rag-2-CD38 double KO mice and were analyzed for cADPR content. Three separate purifications and analyses were performed on tissues isolated from 3 mice/analysis. *P=0.01, **P=0.07; Anova analysis. Limit of detection, 0.2 pmol/mg protein.

[0131] WT tissues containing primarily lymphoid or myeloid cells, such as spleen, thymus and lymphoid deficient bone marrow (myeloid cells), had easily detectable levels of cADPR. In contrast, cADPR was not detected in lymphoid or myeloid tissues isolated from CD38KO mice. However, the cADPR content of CD38KO tissues such as brain, kidney and heart was nearly equivalent to the cADPR content of the same WT tissues. Thus, other unknown cyclases must be responsible for cADPR production in organs such as brain and heart, however, CD38 is the predominant ADP-ribosyl-cyclase expressed by myeloid and lymphoid cells.

[0132] CD38 deficient mice are more susceptible to bacterial infection. To test the requirement for CD38 and cADPR in innate inflammatory immune responses, CD38KO and WT mice were infected with Streptococcus pneumoniae and assessed survival (Figure 7A). It was observed that

the LD50 for CD38 KO animals is at least 10-fold lower than for WT mice, as 100 colony forming units (CFU) killed 50% of the CD38KO mice within 2.5 days of infection, while 1000 CFU were required to kill 50% of the WT animals in the same time period.

[0133] Since CD38 is expressed by the responding immunocytes and the bronchial epithelium (Fernandez JE et al., J. biol Reg Homeost Agents 12:81-91), WT or CD38KO bone marrow was transplanted into irradiated WT hosts to test whether CD38 expression in the lung and/or immune system was necessary for protection. The reconstituted chimeric animals possessed either CD38+ or CD38-deficient bone-marrow derived cells, while all other cell types, including the bronchial epithelium, were of WT origin in both groups of animals. The reconstituted mice were then infected with *S. pneumoniae* and survival was monitored (Figure 7B). Reconstituted animals receiving CD38KO bone marrow were much more susceptible to infection compared to mice receiving WT bone marrow, indicating that the increased susceptibility of CD38KO mice to *S. pneumoniae* infection is due to the loss of CD38 on bone marrow-derived lymphoid and/or myeloid cells.

[0134] To determine whether the increased susceptibility of CD38KO animals to *S. pneumoniae* was due to an inability to restrain bacterial growth and spreading to systemic sites, CD38KO and WT mice were infected with 1000 CFU of *S. pneumoniae* and bacterial titers were assessed in lung and blood 12 hours post-infection (Figure 7C). The bacterial titer in the lungs of CD38KO mice was increased five-fold compared to WT controls. However, the bacterial burden in the blood of the CD38KO mice was 200-500 times greater than in WT mice, indicating that the

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bacteria rapidly disseminate in CD38KO mice.

[0135] To determine whether myeloid or lymphoid cells were responsible for the increased bacterial spreading, Rag-2 KO mice (Shin Kai, et al., 1992 *Cell* 68:855-867) (which lack lymphocytes but can express CD38 on all myeloid cells) and CD38-Rag-2 double knockout mice (which lack lymphocytes and cannot express CD38 on their myeloid cells) were infected with 1000 CFU *S. pneumoniae* and then bacterial titers were determined in lung and blood 12 hours later (Figure 7C). The bacterial titers in the lungs and blood of the lymphoid-deficient CD38-Rag-2 double KO mice were as high as those seen in the CD38KO mice and were significantly increased when compared to Rag-2 KO or WT mice. Thus, CD38 deficient myeloid cells are responsible for the increased susceptibility of CD38KO mice to *S. pneumoniae*.

[0136] CD38 deficient neutrophils do not accumulate at sites of infection and inflammation. To test whether myeloid cells were appropriately recruited to the lungs of *S. pneumoniae*-infected CD38KO animals, CD38KO and WT mice were infected and then the cells that were recruited to the lung airways after infection were enumerated. The total number of cells in the airways of CD38KO and WT animals increased equivalently from 6 to 18 hours post-infection (Figure 8A). However, neutrophils were the predominant cell type found in the lungs of WT animals 12-18 hours post-infection, while the cellular infiltrate in the lungs of the CD38KO animals was composed primarily of macrophages (Figure 8B-C). Thus, CD38 appears to be required for sustained recruitment of neutrophils to the site of infection and inflammation.

[0137] CD38 deficient neutrophils make a defective chemotactic response to the chemoattractant fMLP. Neutrophils migrate to sites of infection in response to gradients of chemokines and chemoattractants that are produced by the local cells and by the invading pathogen (Hub et al. 1996 *Chemoattractant Ligands and Their Receptors* (ed. Horuk) 301-325 (CRC Press, Boca Raton, FL); Servant G. et al., 2000 *Science* 287:1037-1040; Gao, J.L., 1999 *J. Exp. Med* 189:657-662). Chemoattractants rapidly activate neutrophils and induce random migration (chemokinesis). If a chemotactic gradient exists, the activated neutrophils polarize their leading edge toward the highest concentration of the gradient and migrate directionally16 (chemotaxis). It has been previously demonstrated that neutrophils home to sites of infection upon stimulation of their N-formylpeptide receptor (FPR) by bacterially-derived formylated peptides such as formyl-methionyl-leucyl-phenyalanine (fMLP). To test whether CD38KO neutrophils were defective in their ability to chemotax to fMLP, the ability of CD38KO and WT neutrophils to migrate by chemokinesis and chemotaxis in a transwell checkerboard assay was determined (Falk et al., 1980 *J. Immunol. Methods* 33:239-247) (Figure 8D). When fMLP was absent from the top and bottom chamber, or when fMLP was placed only in the top chamber, few (<2300 cells), but equivalent numbers, of the CD38KO and WT neutrophils migrated to the bottom chamber. When an equal concentration of fMLP was present in the top and bottom chamber (chemokinesis conditions), increased, but similar, numbers of WT and CD38KO neutrophils migrated to the bottom chamber, indicating that activation-induced chemokinesis to fMLP was equivalent between CD38KO and WT neutrophils. When fMLP was present in the bottom chamber only

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(chemotaxis conditions), the migration of WT neutrophils to the bottom chamber was further

increased. However, CD38KO neutrophils migrated only marginally better in the presence of a

chemotactic gradient than in the absence of a fMLP gradient, indicating that CD38KO

neutrophils can be activated to migrate by bacterial chemoattractants but are unable to follow the

chemotactic gradient. To determine if this was a general property of CD38KO neutrophils, the

same experiments were performed using the chemokine IL-8, which is a potent activator of

neutrophils (Baggiolini et al., 1989 *J. Clin. Invest* 84:1045-1049). In contrast to what was

observed with fMLP, the IL-8-induced chemotaxis of CD38KO and WT neutrophils was

equivalent (Figure 8D). Thus, these data indicate that CD38KO neutrophils make defective

chemotactic responses to some, but not all, chemoattractants.

[0138] CD38 is expressed and enzymatically active on neutrophils. Since CD38KO neutrophils

appear to have an intrinsic defect in chemotaxis, CD38 expression and enzyme activity on mouse

and human neutrophils was determined. Neutrophils isolated from the bone marrow and blood

of WT mice clearly expressed CD38 (Figure 9A), and likewise, human peripheral blood

neutrophils also expressed CD38 (Figure 9B). Interestingly, when WT mice were injected

intraperitoneally with the inflammatory agent, thioglycollate, CD38 expression increased

significantly on the neutrophils isolated from the blood and peritoneal cavity (Figure 9D). Next,

to test whether CD38-expressing neutrophils can catalyze the cyclase reaction, WT and CD38KO

neutrophils were incubated with the NAD+ analogue, nicotinamide guanine dinucleotide (NGD),

and then measured the cyclization of NGD into the fluorescent compound cyclic GDP-ribose

(Graeff et al., 1994 *J. Biol. Chem* 269:30260-30267) (cGDPR). As shown in Figure 9C, WT

neutrophils, but not CD38KO neutrophils, produced cGDPR rapidly upon incubation with NGD,

indicating that CD38-expressing neutrophils are competent to produce cyclic nucleotides.

[0139] cADPR and ryanodine induce intracellular calcium release in neutrophils. Since cADPR

induces intracellular calcium release through ryanodine receptor (RyR) gated stores (Galione et

al. 1991 *Science* 253:1143-1146), it was tested whether the RyR/cADPR calcium signaling

pathway was functional in neutrophils. RT-PCR analysis showed that neutrophils express mRNA

for RyR3 (Sorrentino, V. et al., 1993 *TIPS* 14:98-103; Hakamata Y. et al., 1992 *FEBS Lett*

312:229-235), although at levels much lower than seen in the brain (Figure 9D). To test whether

the RyRs expressed by neutrophils were functional, intracellular calcium levels ([Ca2$^+$]i) were

measured in neutrophils that were permeabilized in calcium-free buffer and then stimulated with

ryanodine (Figure 9E). A small, but reproducible, increase in [Ca2$^+$] in ryanodine-stimulated

neutrophils that could be blocked by the RyR inhibitor, ruthenium red was observed (Galione et

al. 1991 *Science* 253:1143-1146). Next, to test whether cADPR could induce intracellular

calcium release in neutrophils, neutrophils were permalized in calcium-free buffer and then

stimulated the cells with purified cADPR (Figure 9F). A small, but easily detectable, rise in

intracellular free calcium was observed. No calcium release was observed when the cADPR was

first hydrolyzed by heat inactivation (Lee et al., 1989 *J. Biol. Chem.* 264:1608-1615) or when the

cells were pre-treated with 8-Br-cADPR, an inactive analogue of cADPR that competitively

antagonizes cADPR binding to RyRs (Guse et al., 1994 *Annu. Rev. Immunol* 12:593-633). The

specificity of the antagonist, 8-Br-cADPR, for cADPR mediated calcium release was further

demonstrated by showing that 8-Br-cADPR was unable to block the accumulation of intracellular

free calcium mediated by thapsigargin (Figure 9G). Together, the data demonstrate that

intracellular calcium can be released through RyR and cADPR-mediated mechanism in

neutrophils.

[0140] CD38 catalyzed cADPR is required for extracellular calcium influx in fMLP-activated

neutrophils. Signaling through chemokine/chemoattractant G-protein coupled receptors such as

FPR and the IL-8 receptors results in increased $[Ca2^+]i$ due to a combination of intracellular

calcium release and extracellular calcium influx (Murphy, P.M., 1994 *Annu. Rev. Immunol*

12:593-633; Demaurex N. et al., 1994 *Biochem J.* 297:595-601; Schorr W. et al., 1999 *Eur. J.*

Immunol 29:897-904: Lew et al., 1989 *Eur. J. Clin. Invest.* 19:338-346). Since CD38KO

neutrophils were defective in chemotaxis assays to fMLP and lacked the ability to produce the

calcium mobilizing metabolite, cADPR, it was hypothesized that calcium mobilization in

response to fMLP would be deficient in CD38KO neutrophils. To test this, CD38KO or WT

neutrophils were stimulated with fMLP or IL-8 in calcium-free media and intracellular calcium

release was measured (Figure 10A). An immediate sharp rise in intracellular calcium was

observed that gradually declined over next 5 minutes in fMLP-stimulated WT neutrophils. In

contrast, in fMLP-stimulated CD38KO cells, the magnitude of $[Ca2^+]i$ after fMLP stimulation

was reduced by approximately 20% and the $[Ca2^+]i$ declined to baseline at least 2 minutes

earlier. Unlike the reduced $[Ca2^+]i$ found in fMLP-stimulated CD38KO neutrophils, the $[Ca2^+]i$

of IL-8 stimulated CD38KO and WT neutrophils was identical. Thus, these data suggested that CD38 may be necessary for optimal intracellular calcium release after fMLP, but not IL-8, stimulation.

[0141] Next, to assess whether CD38 was required for extracellular calcium influx, stimulated CD38KO or WT neutrophils were stimulated with fMLP or IL-8 in calcium-containing media (Figure 10B). When we added fMLP to WT neutrophils, a rapid increase in $[Ca2^+]i$, due to intracellular calcium release was observed, as well as a second extended, increase in $[Ca2^+]i$, due to extracellular calcium influx. In striking contrast, the calcium influx phase of the response was essentially ablated in the fMLP-stimulated CD38KO neutrophils. Interestingly, when WT and CD38KO neutrophils were stimulated with IL-8 in calcium containing media, it was found that IL-8 induced a equivalent immediate increase in $[Ca2^+]i$ that rapidly declined to baseline levels in both WT and CD38KO neutrophils, indicating that IL-8 did not induce extracellular calcium influx in either WT or CD38KO neutrophils.

[0142] To determine whether cADPR regulates calcium mobilization in fMLP stimulated neutrophils, CD38KO and WT neutrophils were preincubated with increasing concentrations of the cADPR antagonist, 8-Br-cADPR, and then stimulated with fMLP or IL-8 (Figure 10C). When 8-Br-cADPR-treated WT cells were stimulated with fMLP, the release of intracellular calcium as well as the influx of extracellular calcium was reduced in a dose-dependent fashion to the levels seen in CD38KO cells. In contrast, addition of 8-Br-cADPR to IL-8 stimulated neutrophils had absolutely no effect on the $[Ca2^+]i$ of either WT or CD38KO neutrophils.

Together, these data indicate that CD38-produced cADPR regulates intracellular calcium release and extracellular calcium influx in response to fMLP, and that neither CD38 nor cADPR are necessary for calcium mobilization in IL-8 stimulated neutrophils.

[0143] CD38 catalyzed cADPR is required for neutrophil chemotaxis to fMLP but not IL-8. To test whether cADPR-mediated calcium mobilization is required for chemotaxis to fMLP, WT neutrophils were preincubated with either EGTA or 8-Br-cADPR and then chemotaxis to fMLP or IL-8 in a checkerboard chemotaxis assay was measured (Figure 10D). When WT neutrophils (no pre-treatment) were incubated with media in the top chamber and fMLP or IL-8 in the bottom chamber, the cells efficiently migrated to the bottom chamber. However, if the extracellular calcium was chelated with EGTA or if the cells were pre-treated with the cADPR antagonist, 8-Br-cADPR, chemotaxis of the WT neutrophils to fMLP was reduced by more than 80%. Importantly, EGTA or 8-Br-cADPR treatment had absolutely no effect on the ability of neutrophils to chemotax to IL-8. Thus, extracellular calcium influx, regulated by cADPR-mediated intracellular calcium release, is necessary for fMLP-induced chemotaxis of neutrophils.

[0144] An analogue of NAD+ inhibits neutrophil chemotaxis to fMLP, but not IL-8, in a CD38-dependent fashion. Since CD38 catalyzed cADPR appeared necessary for neutrophil chemotaxis to fMLP, it was predicted that chemotaxis could be inhibited by treating neutrophils with NAD^+ analogues that could be converted by CD38 into antagonists of the cADPR signaling pathway. To test this prediction, neutrophils with pretreated with nicotinamide 8-bromoadenine dinucleotide ($N(8-Br-A)D^+$), a substrate that can be converted by CD38 into 8-Br-cADPR, the

cADPR antagonist that was used in our earlier experiments. To first test whether $N(8\text{-Br-A})D^+$

altered extracellular calcium influx in fMLP-activated neutrophils, WT neutrophils were

pretreated with $N(8\text{-Br-A})D^+$, the cells were stimulated with fMLP and then $[Ca2^+]i$ was

measured (Figure 11A). $N(8\text{-Br-A})D^+$ pre-treatment inhibited the entry of extracellular calcium

in fMLP-treated neutrophils. Next, WT and CD38KO neutrophils were pretreated with $N(8\text{-Br-}$

$A)D^+$ or left in media alone, followed by testing for their ability to chemotax to fMLP (Figure

11B) or IL-8 (Figure 11C). Untreated WT neutrophils chemotaxed to both fMLP and IL-8, while

untreated CD38KO neutrophils could not chemotax to fMLP, but could chemotax to IL-8.

Interestingly, pre-treatment of WT neutrophils with $N(8\text{-Br-A})D^+$ severely reduced neutrophil

chemotaxis to fMLP but had no effect on their ability to chemotax to IL-8. Pre-treatment of the

CD38KO neutrophils with $N(8\text{-Br-A})D^+$ had no effect on the chemotaxis of the CD38KO

neutrophils to either fMLP or IL-8, indicating that the $N(8\text{-Br-A})D^+$ induced inhibition of fMLP-

mediated chemotaxis was CD38 dependent. Together, the data demonstrate that NAD^+

analogues can regulate calcium responses and chemotaxis of neutrophils in a CD38-dependent

fashion.

7. EXAMPLE: MOUSE MODEL OF ALLERGIC LUNG DISEASE AND ROLE OF CD38

[0145] The subsection below describes data demonstrating that CD38-deficient eosinophils are

unable to be recruited to the site of airway inflammation induced by allergens.

7.1. MATERIALS AND METHODS

[0146] OVA priming and sensitization. C57BL/6 WT mice were immunized intraperitoneally with 20 µg chicken ovalbutnin (OVA) adsorbed to alum. Immunized mice were sacrificed 30 days post-immunization and the OVA-primed CD4 T cells were purified from the spleen using MACS magnetic beads that were directly conjugated with anti-CD4. Naive CD4 T cells were purified using anti-CD4 conjugated MACS beads from unimmunized C57BL/6 WT mice. Naive or OVA-primed T cells were injected intravenously into either C57BL/6 WT or CD38KO recipients at 1 x 10^7 CD4 T cells per mouse to generate 4 groups of 10 mice each indicated in Figure 11 A and B. Recipient mice were then sensitized intratracheally with 10 µg OVA in PBS on each of 7 consecutive days immediately following T cell transfer. Mice were sacrificed on the eighth day after T cell transfer, and infiltrating cells were removed from the airways and alveoli of the lungs by broncheoalveolar lavage as described in Section 6.2.2, *supra*. Total cells were then enumerated by counting on a hemocytometer and differential cell counts were performed by centrifuging cells on to a glass slide, staining with Diff-Quick and identifying at least 200 cells per slide at 400X.

7.2. RESULTS

[0147] To determine if CD38 controls the recruitment of cells other than neutrophils to the lung, a mouse model of allergic lung disease that mimics many of the properties of human asthma was used (Lloyd CM et al., 2001, Adv. Immunol. 77:263-295). An important component of asthma is

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airway inflammation, which is thought to be induced or exacerbated by the activities of

eosinophils that have been recruited to the lung. Although eosinophils are primarily responsible

for the pathology of asthma (Broide, DH et al., 1991, J. Allergy Clin. Immunol. 88:637-648),

their recruitment and function appears to be controlled by T cells that have been primed to

allergenic antigens (Gavett et al., 1994, Respir. Cell Mol. Biol. 10:587-593). Such T cells often

produce type 2 cytokines, such as IL-4, IL-5 and IL-13, as well as chemokines like eotaxin

(Cohn, L. et al., 1988, J. Immunol. 161:3813-3816; Drazen JM et al., 1996, J. Exper Med. 183:1-

5). To examine the ability of CD38 to regulate eosinophil recruitment independently of any

effects of CD38 on T cell activation, WT mice were immunized with the antigen OVA. After 30

days, CD4 T cells from these OVA-primed mice were transferred to either WT or CD38KO

recipients. As a control, naive CD4 T cells were transferred from unimmunized WT mice to

either WT or CD38KO recipients. Recipient mice were then sensitized intratracheally with 10

μg of OVA in PBS on each of eight consecutive days immediately following T cell transfer.

Mice were sacrificed on the ninth day after T cell transfer and the cells in the airways of the lungs

were enumerated.

[0148] As seen in Figure 12A, substantial numbers of neutrophils were recruited to the airways

of WT mice regardless of whether they received naive or primed CD4 T cells. In contrast,

although CD38KO trice that received primed T cells did have significantly more neutrophils in

the airways than CD38KO mice that received naive T cells, relatively few neutrophils were

recruited to the airways of CD38KO mice compared to the airways of WT mice. Thus,

neutrophil recruitment to the lung in a model of allergic airway disease is also dependent on the expression of CD38.

[0149] Strikingly, the recruitment of eosinophils to the airways of OVA-sensitized mice was dependent on the presence of both primed CD4 T cells and the expression of CD38. As seen in Figure 12B there was a 30-fold reduction in the numbers of eosinophils recruited to the lungs of CD38KO mice that had received primed CD4 T cells relative to that in WT mice that had received primed CD4 T cells and a 10-fold reduction in the numbers of eosinophils recruited to the airways of CD38KO mice that received naive CD4 T cells relative to that in WT mice that had received naive CD4 T cells. Therefore, the recruitment of eosinophils to the lung in a model of allergic airway disease is also dependent on CD38.

8.   EXAMPLE: CLONING OF *SCHISTOSOMA MANSONI*
                 CD38 HOMOLOGUE

[0150] The subsection below describes the cloning and sequencing of a *S. mansoni* CD38 homologue referred to as SM38. Helminths, such as *S. mansoni*, are broadly defined as worm parasites that infect and can cause pathogenesis in most invertebrates, vertebrates and plant species. The genus *Schistosoma* consists of parasitic flatworms whose definitive habitat is the bloodstream of warm-blooded vertebrates. Four species of *Schistosoma*, including *S. mansoni* cause disease in 200-400 million humans per year and kill up to 1 million people each year (WHO, 1996). Additionally, at least two *Schistosoma* species infect domesticated cattle and sheep causing serious economic losses. Thus, it would be beneficial to develop effective

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antibiotic drugs that could be used to treat infected humans and/or animals. The pathogenesis of

Schistosoma infection is caused mainly by the deposition of eggs by the mature worm into

various tissues and organs of humans and animals where granulomas then form leading to

fibrosis and tissue damage. However, the cercariae (immature worm) and fully mature worm

also release a number of proteins and lipid mediators that can also induce an immune

inflammatory response (Fusco, AC et al., 1991, J. Paristol. 77:649-657). The treatment of choice

in schistosomaisis is the drug praziquantel which appears to induce calcium influx across the

tegument of the worm causing immediate muscle contraction and paralysis (Kohn, AB et al.,

2001, J. Biol. Chem 276:36873-36876). Thus, drugs that modulate schistosome calcium

responses, particularly within the muscle, might be effective in the treatment of this disease.

8.1.   MATERIALS AND METHODS

8.1.1. CLONING OF SHISTOSOMA MANSONI CD38 HOMOLOGUE

[0151] Primers were made corresponding to the EST sequence found in Genbank accession

#AW017229. (5' primer: acatctttgtggtactgaatggctcgg and 3' primer:

tgagtaatgtctcgacgtttgacctcg).   S. mansoni cDNA libraries were obtained from Dr. Phillip

LoVerde (SUNY, Buffalo), and were subjected to PCR using the primers indicated above. The

library (1-20 µl) and dH2O were heated to 70^0C for 10 minutes and were then combined with the

remainder of the PCR reagents and cycled. The cycles were: 95^0C 5 minutes, 1 cycle, followed

by 95^0C 1 minute, 65^0C 1 minute and 72^0C 2 minutes for 35 cycles followed by 1 cycle at 72^0C

for 5 minutes. The expected 330 bp band corresponding to EST AW017229 was isolated, TOPO

cloned, and then used as a probe to screen 250,000 plaques from the *S. mansoni* cDNA library.

Five positives were isolated and then subjected to 3 more rounds of screening in order to produce

plaque pure clones. All five clones were fully sequenced on both strands. The nucleotide

sequence and amino acid translation of four of the clones were identical (referred to as SM38).

The stop codon and polyadenylation sites were identified in all of the SM38 clones, but the

initiation methionine was not present in any of the clones. To obtain the 5' end of the SM38

gene, a single primer extension approach (NAR, 1994, vol 22, No. 16, p3427-3428) was utilized.

A first round of PCR was performed using an external SM38 primer (5'

catcgaataaccctgatttcataacac) and the universal reverse primer for Bluescript. Two μl of this

reaction was then subjected to PCR using an internal nested SM38 primer (5'

gataaagtaagaactcgtgcc) and the universal reverse primer. A 200 and a 300 bp band were

identified from this reaction and were directly sequenced. The sequence obtained overlapped

124 bp with the 5' end of the SM38 clones and included an additional 153 bp of sequence,

however the no stop codon was detected, indicating that we still did not have the 5' end of the

gene. Therefore, classic 5"RACE (PNAS vol 85 pp 8998-9002, Dec. 1998) was performed using

using cDNA prepared from RNA isolated from adult *S. mansoni* worms (RNA provided by Dr.

P. LoVerde, SUNY Buffalo). 10X Taq buffer, dNTP's, cDNA and Expand High Fidelity Taq

were combined with the dT-AP primer (see ref. For details) and cycled for 5 minutes at 95°C

followed by 2 minutes at 50°C and 40 minutes at 72°C. After this 40 minute incubation the 5'

external SM38 primer (see above) and AP primers were added and cycled for 35 cycles under the

conditions: 95°C for 15 sec, 47°C for 30 sec, 72°C for 2 minutes followed by a 5 minute

extension at 72°C. The reactions were run on a 1.5% agarose gel and a 300 bp band was isolated

using Qiagen Gel Kit. The 5' RACE product was directly sequenced with the AP and 5' external

SM38 primer. Two potential initiation methionines were identified in the sequence and two stop

codons were found 13-19 amino acids upstream of the methionine residues. The RACE product

was subsequently cloned. All three clones containing SM38 sequence (Two PCR generated

clones and one clone from the S.mansoni cDNA library) were contiguous and overlapping.

When assembled, the SM38 sequence included 1049 bp of sequence including 5' untranslated

sequence, two potential initiation methionines, an open reading frame encoding a 303 amino acid

protein, a stop codon, 3' untranslated sequence and a poly-adenylation site.

8.2.   RESULTS

[0152] Since drugs that modulate calcium responses in the muscle fibers of Schistosomes appear

to be effective anti-helminth reagents (Kohn et al, 2001, J. Biol. Chem. 276:36873-36876), we

set out to identify specific calcium modulating targets of Schistosomes. It has been recently

shown that Schistosomes express Ryanodine Receptors (RyR) within their muscle fibers (Day et

al., 2000, Parasitol. 120:417-420; Silva et al., 1998, Biochem. Pharmacol. 56:997-1003).

Agonists of RyRs expressed in vertebrate smooth and skeletal muscle are known to regulate

intracellular calcium release, voltage gated calcium influx and muscle contractility. Interestingly,

S. mansoni muscle fibers treated with RyR agonists such as caffeine induced the release of

intracellular calcium and induced contraction of the muscle fiber. Although drugs such as

caffeine can modulate RyR-dependent calcium responses, the physiological modulator of RyRs,

at least in vertebrate muscle fibers is cyclic ADP-ribose (cADPR). cADPR is a known calcium

mobilizing metabolite that is produced by ADP-ribosyl cyclase enzymes such as the mammalian

CD38 protein and the invertebrate Aplysia cyclase enzyme. To determine whether Schistosomes

express an enzyme capable of producing the calcium mobilizing second messenger, cADPR, a

search was performed of the publicly available EST sequences looking for Schistosome

sequences that when translated would have homology to the mammalian CD38 and Aplysia

enzymes. Three EST sequences (EST AI067047, EST AW017229 and EST N20756) were

identified that could be assembled into a contiguous and overlapping sequence (Fig13). This

assembled sequence shared limited but significant homology with both CD38 and the Aplysia

cyclase enzymes.

[0153] To determine whether the assembled ESTs actually represented an authentic cDNA,

primers were prepared from the sequence of EST AW017229 and performed PCR on a *S.*

mansoni cDNA library. A 330 base pair fragment was isolated from the PCR reaction and was

sequenced. As expected the sequence of the fragment matched that of the EST. The fragment

was then used as a probe to screen 250,000 plaques from the *S. mansoni* cDNA library. Five

independent plaques which hybridized to the EST probe were isolated, plaque purified and

sequenced on both DNA strands. The sequence information was then used to design additional

primers to isolate the 5' end of the cDNA (see methods). The complete cDNA sequence isolated

from the *S. mansoni* library was then assemble and compared to the ESTs. The alignment, shown in Figure 13, indicates that the contiguous assembly of the EST sequences was correct and that the cloned cDNA (referred to as SM38) included at least an additional 421 base pairs of sequence not found in any EST. Translation of the DNA sequence gave rise to a 299 amino acid sequence (Figure 14) containing structural motifs typical of cyclase enzymes (Prasad, GS, 1996 Nature Struct. biol. 3:957-964). In particular, the SM38 protein contains conserved amino acid residues that align with critical catalytic and active site residues found in the Aplysia cyclase enzyme (Munshi C, et al., 1999, J. Biol. Chem. 274:30770-30777) and in mammalian CD38 (Munshi C, et al., 2000, J. Biol. Chem. 275:21566-21571; Graeff R., 2001, J. Biol. Chem. 276:12169-12173)(Figure 15A-B). Additionally, cysteine residues that are critical for the assembly of the tertiary structure of the cyclase enzymes (Prasad GS, et al., 1996, NAture Struct. biol. 3:957-964)are also conserved in SM38 ; (Figure 15A-B). Importantly, the SM38 cDNA sequence encodes for a complete cyclase enzyme domain (Figure 16).

[0154] Based on these results, we have shown that Schistosomes such as *S. mansoni* encode a protein (SM38) that is highly homologous at the structural level to enzymes that are capable of catalyzing the production of the calcium mobilizing second messenger, cADPR. Since Schistosomes also express RyRs which release intracellular calcium in response to cADPR, it is predicted that SM38 will be able to regulate calcium response in Schistosomes. Furthermore, since regulation of calcium influx, particularly in Schistosome muscle fibers can result in paralysis and clearance of the worm, we predict that agonists/antagonists of the SM38 and RyR

pathways in Schistosomes may be effective as anti-helminth drugs.

[0155] The present invention is not to be limited in scope by the specific embodiments described herein which are intended as single illustrations of individual aspects of the invention, and functionally equivalent methods and components are within the scope of the invention. Indeed, various modifications of the invention, in addition to those shown and described herein will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Such modifications are intended to fall within the scope of the claims. Various publications are cited herein, the contents of which are hereby incorporated, by reference, in their entireties.